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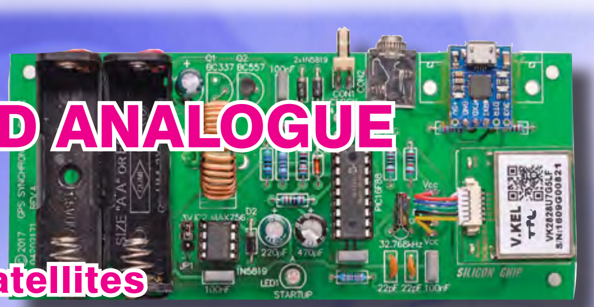

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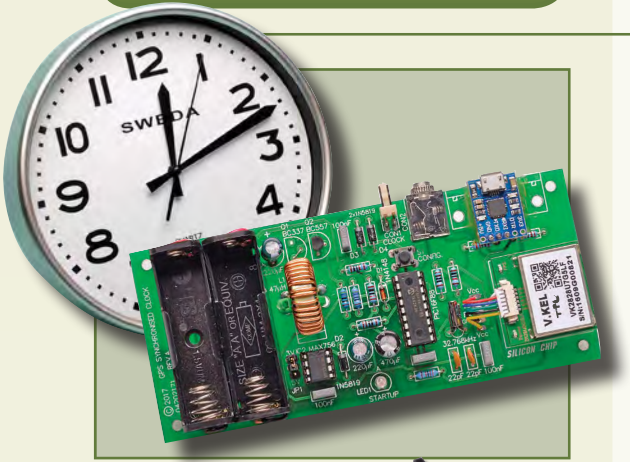

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Our March 2018 issue will be published on Thursday 1 February 2018, see page 72 for details.

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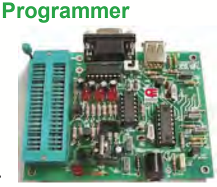

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Super-accurate analogue clock

We all appreciate the superb precision of digital clocks, but they do tend to lack a certain something when it comes visual 'warmth' – you can't imagine a digital clock becoming a much-loved family heirloom in the way that a beautiful old grandfather timekeeper might. On the other hand, that accuracy is pretty much vital these days – and they don't need winding up!

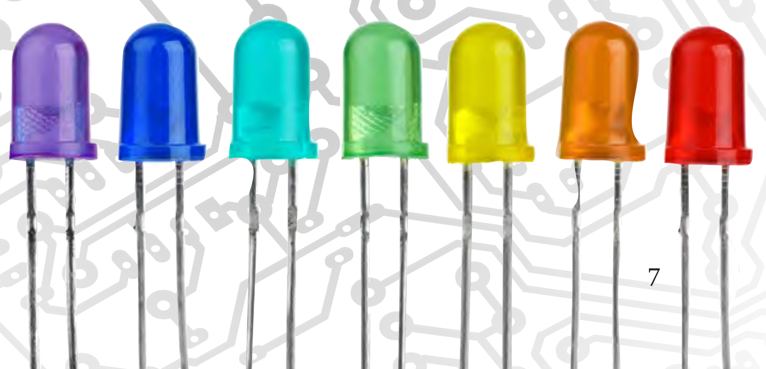
True, there are analogue clocks driven by digital technology, but they usually lack the super accuracy of GPS-synchronised clocks. Not anymore though – now you can have the best of both worlds with our super-accurate *GPS-synchronised Analogue Clock Driver*. Not only will it let you have the standard accuracy of an ordinary quartz-driven analogue clock, but now it will even synch up with satellite time and take account of your local Daylight Saving Time protocols. I hope you enjoy reading this project, and of course building it.

Thank you Max

You will see from this month's *Cool Beans* that sadly we must say goodbye to our resident blogger, tinkerer, design guru and world-renowned Hawaiian shirt expert, Clive 'Max' Maxfield. There are only so many crazy designs, international conferences and websites that any one man can be master of, and so Max has (reluctantly) decided that he needs to focus on slightly fewer projects and has penned his final column for *EPE*

Max has been writing in *EPE* for nearly eight and half years and by my reckoning he must have notched up the best part of a century of contributions. Despite residing in Alabama for the last few decades, his Sheffield accent reveals his true roots, and so, as befits a true Yorkshireman, he retires 100 – *not out*.

Thank you Max for all your fantastic articles and truly terrible jokes – we wish you the best of luck for the future.



Rebooting high fidelity in digital music – report by Barry Fox

'Fix the music and the hardware will look after itself', Bob Stuart, founder of Meridian Audio and creator of MQA (the Master Quality Authenticated system for online audio distribution), told the fourth annual Futuresource Audio Collaborative conference held in London in November.

Stuart was taking part in a panel discussion on the 'World of Luxury Audio'. While fellow panellists including Stuart Tickle, managing director AWE Europe (smart home technology distributor and trade trainer) and Victor d'Allancé, general manager UK and Ireland, Devialet, the French top-end audio company, debated the meaning of 'luxury' as 'something to be proud of', Stuart took a different, simpler line. 'When the music source is high quality there will be an incentive for manufacturers to make audio equipment that does it justice. It is not a matter of pride, it's a matter of enjoyment.'

'This is terribly important', he explained after the event. 'With vinyl they made the record once, as well as they could. Then digital convenience became the selling point, and the record companies had to find ways of reducing the data rate and bandwidth to cope with the storage and transmission technology available at the time. One record company had to make 56 different digital file types – one short of Heinz's '57 varieties'.

'It was a disaster for audio. A whole generation now thinks it is normal for sound to come out of one-inch speakers. But with MQA coding we can get music out of a cell phone with the sound quality of a studio. When the signal has been properly received and decoded an LED light comes on. Once you have convenience and quality we can stop the discussion.

Accessing assets

'The challenge for us is no longer the technology; it's getting the assets. The three majors – Warner, Universal and Sony – have been amazing. We have now finished MQA-encoding all their 24-bit masters. That's 20,000 albums, all at 1Mbps or less. It's taken a year. By 1 December 2017 we will have encoded 1.5 million, 16-bit songs.'

Sonos One – a smart speaker that listens to your commands with six directional microphones. Its noise-cancelling technology enables it to hear during loud music.

Bob Stuart then revealed that MQA is now developing hardware to enable live encoding, on the fly. Whereas coding existing recordings involves several stages, or passes, the live encoder has to do everything in one pass.

'This is important for radio and live music event streaming. We have had radio for around a hundred years and it went from AM to FM and then to rubbish, with low quality DAC chips. People think the sound of reproduction is the sound of a kitchen radio. This is the reboot of audio'.

Opening up Sonos

In an earlier keynote speech, Adriaan Thierry, managing director EMEA and AMPAC, Sonos, had sought to dispel the notion that Sonos is more about luxury, style and convenience than audio substance. Sonos is now opening a showroom in London's Covent Garden, which is modelled on its venue in New York and has 'acoustically designed' listening rooms.

Although the Sonos platform has so far been proprietary and 'closed', Thierry revealed that over the past year Sonos has been piloting a more open approach, with 100 developers experimenting with interfaces to mesh Sonos with other products. In 2018, he said, Sonos will open the platform to anyone, with a certification and licence scheme that lets third parties mark their products 'Works with Sonos'.

Sonos was 'taken by surprise' at the speed with which voice control caught on with consumers, Adriaan Thierry admitted, and is already opening its platform to Alexa, Google and Apple Siri. The challenge, he said, was to make a Sonos speaker play loud, but still hear voice commands. The recently launched Sonos One, he said, has six microphones pointing in different directions, with noise cancellation.

The next step, he says, is to let owners play music whose title they cannot remember, by describing the record sleeve. 'Play the album with the red cover art', he gave as an example.

But Sonos has 'no plans' for mobile devices, Adriaan Thierry confirmed, 'because there are still many millions of homes to equip'.

High-end portable

Meanwhile, another company has joined the MQA fold. British Hi-Fi company iFi Audio (sister to high-

Rebooting high fidelity in digital music – *continued*

end audio manufacturer Abbingdon Music Research) specialises in high-end DACs and portable listening accessories, and has incorporated MQA out of the box in its new Nano iDSD Black Label battery-powered portable DAC and headphone amplifier.

Nano supports PCM up to 32-bit/384kHz and quad-rate DSD at 256 times the CD sampling rate, with dual-mono analogue amplification and 'High Res' certification by the Japan Audio Society. The Black Label tag is a nod to top-end Scotch Whisky, and the price is £199. Battery life is claimed to be 10 hours, with no drain on an iPhone or Android mobile when connected by standard OTG (On The Go) USB A-type cables.

The Nano also incorporates the same technology that is used in Ear Buddy, a recently launched small plug-and-play socket device that attenuates the output of a music portable without losing resolution. iFi says it designed Ear Buddy because modern music portables typically have a digital volume control, which loses two bits when controlling volume. So 16-bit CD resolution is reduced to 14 bits when the digital volume control is set at 60 per cent for comfortable listening. Ear Buddy attenuates the output by 15dB, allowing digital control to be set at full volume.

Ear Buddy costs £20, but the Nano Black Label has two headphone outputs, one with the Ear Buddy-style attenuation built-in and one without. The Nano has an analogue volume control, so the user can set the mobile digital volume on 100% and manually adjust listening volume level in the analogue domain, without losing bits.

Power from graphene

Physicist Paul Thibado, at the University of Arkansas has discovered that graphene has naturally occurring ripples as its atoms vibrate in response to ambient temperature. He says, "This is key to using the motion of 2D materials as a source of harvestable energy". Unlike atoms in a liquid, which move in random directions, atoms connected in a sheet of graphene move together (the ripples). This means their energy can be collected using existing nanotechnology.

Thibado has started designing a device that can turn this energy into electricity using a negatively charged sheet of graphene suspended between two metal electrodes. When the graphene flips up, it induces a positive charge in the top electrode, and when it flips down, it charges the bottom one, creating an alternating current.

Mighty trio prepares for electric flight take off

Airbus, Rolls-Royce, and Siemens have formed a partnership to develop a flight demonstrator which will be a significant step forward in hybrid-electric propulsion for commercial aircraft.

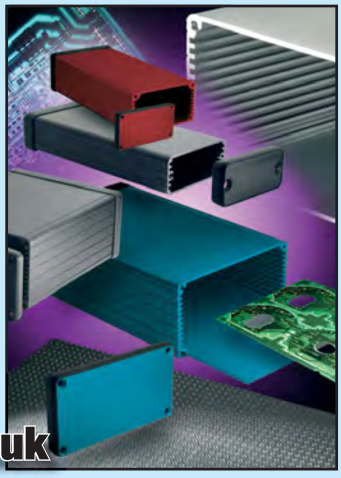
The E-Fan X hybrid-electric technology demonstrator is anticipated to fly in 2020 following comprehensive ground tests, provisionally on a BAe 146 flying testbed, with one of the aircraft's four gas turbine engines replaced by a 2MW electric motor. A second gas turbine will be replaced with an electric motor once system maturity has been proven.

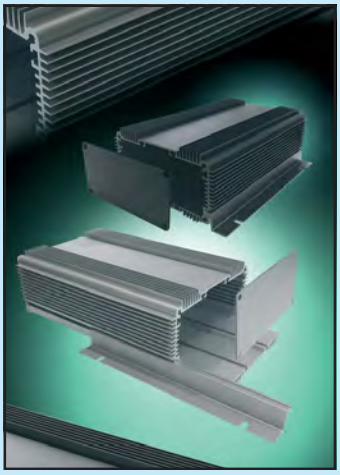
The E-Fan X will explore the challenges of high-power propulsion systems, such as thermal effects, electric thrust management, altitude and dynamic effects on electric systems and electromagnetic compatibility issues.

Each partner will contribute with their extensive experience in their respective fields of expertise. Airbus will be responsible for overall integration, as well as the control architecture of the hybrid-electric propulsion system and batteries, and its integration with flight controls. Rolls-Royce will be responsible for the turbo-shaft engine, 2MW generator, and power electronics. And Siemens will deliver the 2MW electric motors and their power electronic control unit, as well as the inverter, DC/DC converter, and power distribution system.

Paul Stein, Rolls-Royce, chief technology officer, said: 'The E-Fan X enables us to build on our wealth of electrical expertise to revolutionise flight and welcome in the third generation of aviation. This is an exciting time for us as this technological advancement will result in Rolls-Royce creating the world's most powerful flying generator.

The partners aim to meet the EU technical environmental goals of the European Commission's Flightpath 2050 Vision for Aviation (reduction of CO2 by 75%, reduction of NOx by 90% and noise reduction by 65%).





Optimise Your Power Delivery Solutions

UPD360 - USB Power Delivery Controller

Microchip's Power Delivery (PD) Controller, UPD360, is a USB-IF certified USB Type-C™/PD Controller. UPD360 integrates the functional blocks required for USB Type-C and PD communications, which includes V_{CONN} FETs and port power controllers. UPD360 can operate in a standalone mode or a companion mode, interfacing to MCUs, embedded controllers or USB hubs over I^2C/SPI interface. UPD360 can be designed into applications that require USB connectivity, alternate protocols (viz. Display Port) and manage power (as a Source or Sink) up to 100 W over USB Type-C connectors.

Highlights

- USB Type-C and power delivery functionality
- Integrated power switch
- Integrated V_{CONN} FETs
- Dead battery support
- I^2C/SPI interface

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TechnoTalk

Old names for new

Mark Nelson

Two iconic brand names from the past have just been resuscitated, even though there's nothing retro about the products they are being applied to. Is it synchronicity? Or just nostalgia for the good old days? Read on and make up your own mind!

REMEMBER THE SLOGAN 'FINE Sets, these Fergusons'? No? That's a shame, because I certainly do. When I was a youngster we had a large Ferguson mains radio – I listened to the Home and Light programmes, and 'Your Station of the Stars', Radio Luxembourg.

So what's afoot? Well, as mentioned briefly in last month's *News* section, British TV manufacturer Cello Electronics, which makes all of its products at its Bishop Auckland factory, has relaunched the Ferguson brand in the UK. Initially, the name will be applied to 4K UHD TVs, fitted with 50 to 75-inch LED screens. The company is already well established in a number of niche markets, and made the headlines when it brought out the world's first solar powered TV. The 22-inch LED set has built-in CAM/card decryption, making it ideal for use in Africa, where TV channels are scrambled and no mains electricity is available in remote areas. It also has a USB port that can be used for mobile phone charging.

Back in the 1960s, 70s and 80s, Ferguson was a major brand in consumer electronics, when it was part of the Thorn EMI empire. After being acquired by Thomson of France, the brand's presence began to slip and it ended up with Technicolor of France. For Brian Palmer, CEO at Cello Electronics, the availability of the Ferguson brand was a clear opportunity for this proudly British manufacturer. As he enthuses: 'I started out in this business selling Ferguson to consumers and truly understand the trust people had in the brand over the years. Having now come full circle, I am proud to have the opportunity to bring this iconic brand back into the UK market.'

Splurge warning

Did you splurge 'loadsamoney' on home automation at Christmas time? No? That's a relief, because now is not the time. That's what a survey by market analysts Juniper Research (effectively) states. Although Amazon Echo, Google Home, Sonos One and (from next year) Apple HomePod will be installed in 55% of US households in two years' time, early adopters will lose out. Juniper argues that hardware and software vendors still have a way to go in making cross-assistant usage smoother and more intuitive. I take this to mean today's implementation is far too clunky, flaky and proprietary (device-specific). Personally, I have no time for intrusive room ornaments listening into my private conversations and Juniper suggests that the majority of voice-based interaction will involve smartphones, not omnidirectional loudspeaker-earwiggers.

Get your Cs for free?

No, it's not money for nothing, but refers to electronics made from entirely natural materials that are free for the gathering. And whereas Theresa May's magic money tree is a purely imaginary concept, the Chinese really do have a magic capacitor tree. In fact, millions of them, as *New Scientist* magazine reported recently. The tree is from the genus *Paulownia*, also known as the Phoenix tree. Many roads in northern China are lined with these trees, which drop copious amounts of leaves that are usually burnt, exacerbating the country's air pollution problem.

But now, a team led by Hongfang Ma at the Qilu University of Technology in Jinan has discovered a way of turning phoenix tree leaves into organic capacitors. These, the magazine says, could be used like batteries to store energy, potentially reducing some of that air pollution into the bargain. And although the manufacturing process releases some carbon dioxide, it is not nearly as much as that yielded from leaf decay or bonfires. Simply explained, the leaves are cleaned and dried, then ground into a fine powder. Boiling the result in water and filtering out any ash or contaminants produces a brown powder of carbon microspheres. Further treatment makes the carbon material exhibit excellent supercapacitive performance, much better at storing charge than similar supercapacitors made from coal. Fred Cannon at Penn State University in the USA is not convinced, however, and fears that the natural inconsistency in leaf properties might make the idea hard to commercialise. 'Leaves are less consistent in their character,' he states. 'Supercapacitors made from them would be variable in their character, I would anticipate.' He adds that other bio-trash materials have been tried already, including coconut shells, rice husks and banana fibre. Nevertheless, the Chinese supercapacitors made from Phoenix tree leaves outperform those made from other natural materials.

Plessey is back — again!

Some years back, trade paper *Electronics Weekly* cited Plessey as one of the most famous names in semiconductors. The brand vanished after the merger with GEC, which subsequently disappeared as well. The Plessey name lived on in South Africa, where a subsidiary company saw no reason to drop the decades-old name, and it reappeared in the UK when a British distributor brought in its telephone systems from Africa. Now renamed Dimension Data Advanced Infrastructure and part of the Japanese NTT group (formerly Nippon Telegraph and Telephone). It still operates in telecomms (IP telephony and unified communications) but has also expanded into security systems.

Then, in 2013, the Plessey Semiconductors name – and the iconic 'scope trace emblem – were revived to manufacture state-of-the-art semiconductors at the original Plessey-built fabrication facility outside Swindon. And now, using much updated facilities at the plant created by Plessey in the 1980s at Plymouth, it is not just the only LED maker in the UK, but the only LED maker in the world commercially producing LEDs on silicon substrates. Plessey is also a leading expert in the manufacture of semiconductor products used in sensing, measurement and controls applications, and is now at the forefront of the solid-state lighting revolution. For all this, obtaining an existing established brand was critical. The company's current CEO, Canadian Michael LeGoff, is convinced that the Plessey name played a major role, saying: 'It has opened a lot of doors.'

GPS-synchronised Analogue Clock Driver

Design: John Clarke Software: Geoff Graham Words: Nicholas Vinen

Traditional clocks (with hands) are fairly accurate – but every now and then you have to get them down off the wall and adjust them so they show the real time. And daylight saving means you have to adjust it twice a year anyway! Wouldn't it be nice if the clock adjusted itself so it was ALWAYS 100% spot on AND adjusted itself for daylight saving? Build this *GPS Analogue Clock Driver* and your wishes will come true!

Battery-powered quartz crystal clocks are inexpensive, look good hanging on the wall and for many people, they are the preferred way to check the time.

But (despite what many people think) they usually aren't that accurate, drifting by as much as two seconds per day, which means they can be out by up to one minute after a month.

And you have to remember to change them twice a year if you have daylight saving time (DST) in your area. That's especially troublesome if the clock is mounted up high since you need to get up on a ladder or chair to adjust the time. Wouldn't it be nice if you never had to do that again? Well, at least until it's time to change the battery…

This design replaces the electronics in a standard quartz wall clock with a controller that always knows the correct time, thanks to the Global Positioning Satellite (GPS) system.

It uses an inexpensive ($25) GPS module to get the precise time from orbiting atomic clocks and a microcontroller to drive clock hands.

It will run for up to two years on two alkaline AA cells (or one year with a sweep second hand movement) and over that period will keep the time accurate to within one second.

If you don't know the difference between 'sweep' and 'stepped', a sweep second hand appears to rotate in a continuous movement, while a stepped second hand will appear to 'jump', usually in one-second steps.

If your clock has a stepped second hand, you can even program your local DST rules into the clock using a USB cable from your computer and then, when the time comes, the clock will automatically go forward or back by an appropriate amount of time. It does this by either advancing the second hand twice per second, or not at all, until the time shown is correct again.

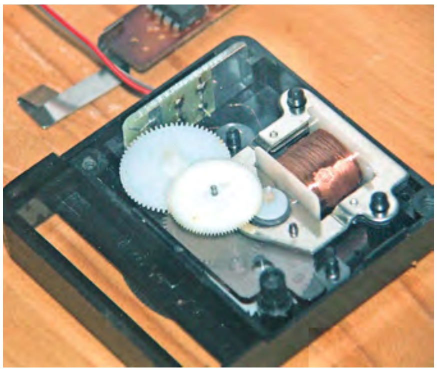


Fig.1: inside a typical quartz clock mechanism with stepped second hand, showing the modifications we made to terminate the connecting leads to the stepper motor coil.

For clocks with step hands, all you have to do is set all three hands to the 12 o'clock position before inserting the battery. The controller will use its onboard GPS module to get the current time and then step the clock hands at high speed around the dial until it has reached the correct time. It will then drop back into normal timekeeping mode with the time derived from a 32,768Hz crystal oscillator.

For clocks with sweep hands, the procedure is similar, but rather than setting it to 12 o'clock, you set it to the next full half hour and the firmware will then wait an appropriate amount of time before driving the clock mechanism, so that the time shown is correct.

To conserve the battery, the GPS module is only used to synchronise the clock every 44 hours and following synchronisation, the clock will either skip seconds or double-step to reach the correct time.

After synchronisation, the microcontroller is also able to calculate the inherent inaccuracy of its crystal oscillator and will then compensate by occasionally skipping or double-stepping

a second, without the GPS module needing to be powered up.

This process can also compensate for aging of the crystal and will keep the clock accurate between synchronisations. This also means that you will probably never even notice the clock making a correction; the time will simply be right!

Battery status monitoring

The controller monitors the battery voltage and when it has dropped below 2V (ie, 1V per cell), the microcontroller will stop the clock at a convenient position.

For clocks with stepped hands, it will stop at exactly 12 o'clock before the battery is so flat that it can no longer drive the mechanism.

You then replace the battery and it will then automatically advance to the correct time again.

For clocks with sweep hands, the firmware will halt the clock at exactly the hour or half-hour position. Before you replace the battery you need to set the hands to the next hour or half hour, but hopefully, you will not have to mess with the second hand because it should have stopped at the exact 12 o'clock position.

Either way, if during operation the GPS signal level drops to a point that is too low for the module to get a lock on enough satellites, the clock will stop at exactly five minutes before the hour/half hour. Similarly, if the GPS module stops running altogether, the clock will stop at 10 minutes before. These indications make it easy to differentiate between a low battery and something more serious. In either event, the firmware will try to acquire a GPS lock again ten times with a 4-hour delay between each attempt before it gives up. This gives the GPS module plenty of opportunities to come good.

Internally, the firmware measures time in eighths of a second. This allows for much finer tracking of errors and control of where the clock's hands are pointing.

Features and specifications

- **Drives virtually any battery-powered quartz clock movement**
- **Works with a sweep or stepped second hand**
- **Long battery life from two AA cells: about one year for clocks with sweep second hand and two years for stepped second hand**
- **Small enough to mount on the back of most clocks**
- **Time synchronised to GPS satellites every 44 hours (configurable)**
- **Can use a variety of GPS modules, including low-cost types**
- **Automatically skips or adds extra seconds to keep clock accurate**
- **Automatically trims internal crystal oscillator based on GPS updates**
- **Automatically sets time when fresh cells are inserted (with stepped second hand only)**
- **Automatically adjusts for Daylight Saving Time (with stepped second hand only)**

Theoretically, it will mean a higher degree of accuracy, although this is offset to some extent by the fact that most clocks with sweep hands will lose a fraction of a second when they start up. This is something that the firmware is not aware of and cannot correct for.

Revised design

Astute readers (or those with long memories!) may recall our original *GPS-synchronised Analog Clock* articles from March 2011 issues, which was for clocks with step hands.

This new design works with either type of movement (step or sweep) and features a number of benefits over the earlier design.

The EM-408 module used in that project is now obsolete and difficult to get; the VK2828U7G5LF module we are using this time is substantially cheaper and has a number of benefits including support for GALILEO (European) and GLONASS (Russian) positioning satellites in addition to the GPS (United States) system.

In fact, it can use satellites from all three systems simultaneously to increase the chance of getting a signal indoors, as a GPS fix relies on receiving signals from multiple satellites (normally at least three).

This module is based on the u-blox Neo-7 chip and has slightly better sensitivity than the previously used EM-408, with a specified tracking sensitivity of –162dBm compared to –159dBm.

It also has a slightly lower current drain, at around 30mA compared to 44mA. Plus it has a faster 'cold start' average time of 26 seconds compared to 42 seconds, meaning it doesn't need to be powered up for as long to get the time.

We have also substantially increased the power efficiency of the GPS module supply. While the GPS module is only powered up about once every two days, it does draw significant current during that time, and so any improvement in efficiency should extend battery life both through draining less charge each time, as well as reducing the temporary voltage drop due to the load on the cells, which may push them below the 1V cut-out threshold.

We have also ditched the old-fashioned DB9/DE9 serial cable and fitted a micro-USB port so that you can

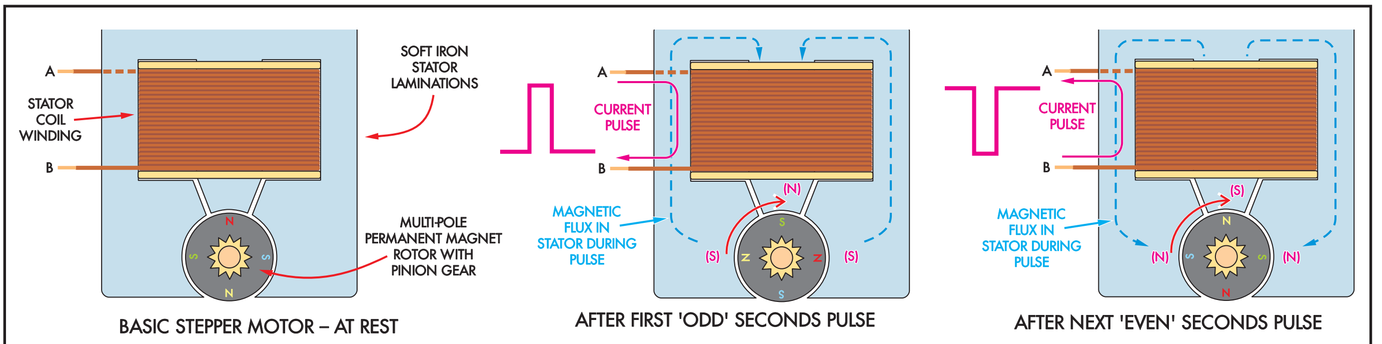


Fig.2: the clock motor consists of a multi-pole permanent magnet rotor inside a circular gap in a soft-iron stator. It's made to step in one direction by reversing the polarity of the current pulse at each step.

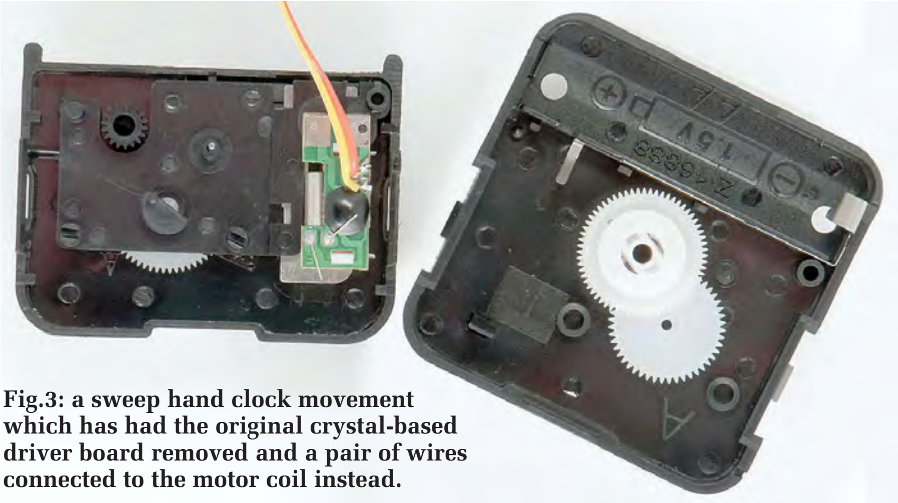


Fig.3: a sweep hand clock movement which has had the original crystal-based driver board removed and a pair of wires connected to the motor coil instead.

easily hook it up to your computer to set up the DST rules and make other setting tweaks.

How it works

A standard battery-operated wall clock uses a crystal oscillator and binary divider to generate a pulse once per second which drives a simple stepper motor and, via gears, the hands of the clock.

The motor consists of a coil with a soft iron core and a small bar magnet (the rotor) positioned in the magnetic field (see Fig.1). When an alternating current flows through the coil, this causes an alternating magnetic field and the rotor rotates to follow this field. It is this rotation that, via gears, drives the clock's hands (see Fig.2).

The crystal oscillator is normally quite accurate, especially when the clock is new – but it's affected by age, temperature and battery voltage, all of which can add up to 14 seconds a week. Our circuit replaces the clock's electronics and generates compatible pulses to drive the stepper motor.

A clock with sweep hands works essentially the same way except that its gearing has a higher reduction ratio, so many more pulses are needed to advance the hands by one second (see Fig.3).

This allows the pulses to be produced more-or-less continuously so the hand moves in a smooth manner. In exchange for a greater battery drain (due to the much higher duty cycle operating the motor), you eliminate the 'tick-tick-tick' noise, making for a much more luxurious timekeeping (and, for some people, sleeping!) experience.

By contrast with the standard clock, at the heart of our circuit is a PIC16LF88 microcontroller which uses a 32,768Hz watch crystal to drive a timer within the chip.

This timer generates an interrupt which is used by the software running on the microcontroller to keep time and also generate pulses to drive the clock motor.

Fig.4 shows how the clock motor is driven by the microcontroller. One end of the clock coil is connected to the junction of the two (nominally) 1.5V cells, while the other end is driven by three paralleled output pins which can momentarily be connected to Vdd, Vss or left open-circuit.

The resulting bipolar waveform for continuous sweep hand clocks has 16 pulses per second, while the waveform for stepping hands is similar but has just one pulse per second (positive or negative).

Fig.5 shows a scope grab of this same waveform, without the mechanism connected, while Fig.6 shows the same waveform with the coil in-circuit.

For clocks with sweep hands, the rotor in the clock's movement has a certain amount of momentum which keeps it spinning while driven by this pulse train, so it never stops. This is different to the stepping clock movement where the voltage pulse on the coil pulls the rotor around and then stops it dead – once every second – thereby creating that ticking sound.

Besides driving the motor, the software also needs to keep track of time, calculate the DST state and time zone offset, as well as periodically power up the GPS receiver and interpret its output.

As a result, the software is really quite complex. As an illustration of this complexity, drafting the circuit took just a few hours, while the software took many weeks to develop.

A normal clock cycle starts at the beginning of each second. The timer generates an interrupt which causes the processor (CPU) in the microcontroller to wake up and execute the interrupt code. The program will perform some calculations (more on this later) and then simultaneously drive output pins 15, 17 and 18 either high or low. It then sets the timer to generate another interrupt after a few tens of milliseconds and promptly puts itself back to sleep.

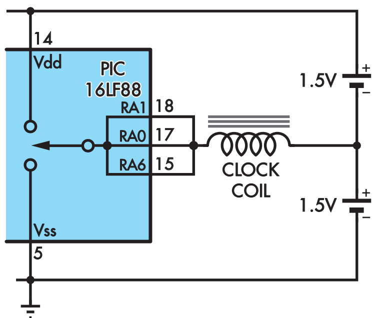
When the timer expires again, it wakes the CPU up and the program sets these outputs back to being high-impedance.

If the clock has a stepping hand, its job is done and it can wait until the next 'tick' and repeat the whole process. But if it has a sweep hand, it will set the timer to wake up again after another short period to deliver the next driving pulse.

During the sleep period, everything except the crystal oscillator and the timer is shut down, resulting in a current drain of only a few microamps by the microcontroller.

In addition, the CPU in the microcontroller will run at full speed for only 60-100µs while processing an interrupt, so the total current drawn by the microcontroller is negligible.

Most of the current, in fact, is drawn by the clock stepper motor – which is the case with a 'standard' battery-



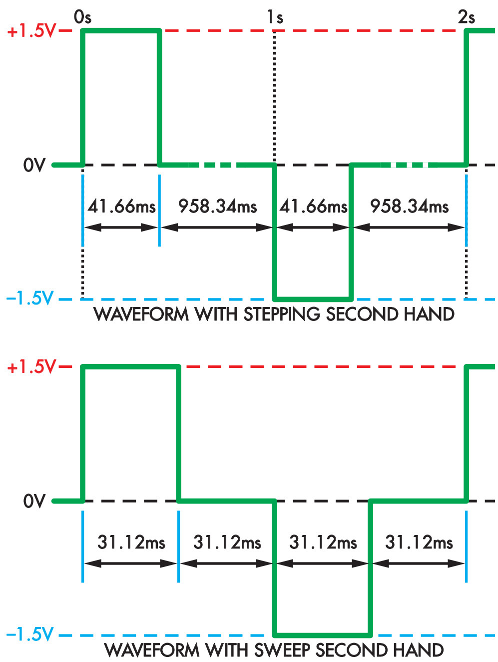


Fig.4: the new driving arrangement for the clock motor. With this configuration, the microcontroller can apply positive or negative pulses of 1-1.5V amplitude to the coil. Three outputs are connected in parallel for better drive strength. The output waveform for stepped second hands is shown at top and sweep at bottom. Pulse durations can be adjusted in the set-up menu.

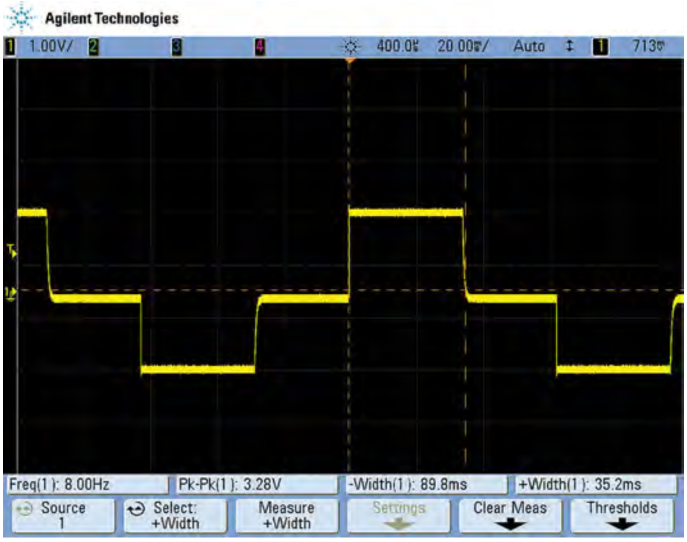


Fig.5: this scope screen grab shows the output signal from pins 15, 17 and 18 of microcontroller IC1 with no load connected and is measured with the centre point of the cells as the ground reference.

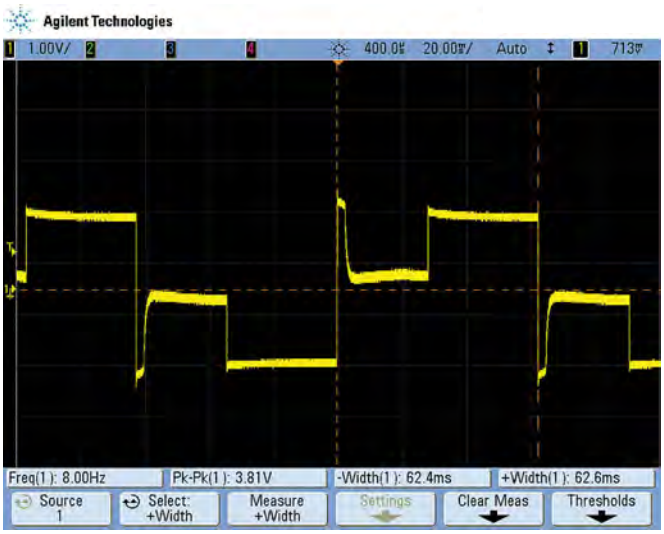


Fig.6: the same measurement as in Fig.5 but with the clock movement connected. The voltage spikes are created by the motor's inductance each time the drive current is reduced to zero. They are clipped by schottky diodes D3 and D4.

operated clock (see the box: Calculating Battery Life).

At the start of each second, the program compares where the clock hands are actually positioned and where we would like them to be. Depending on the result of this comparison, the program may bring the clock's hands closer in agreement to the correct time by skipping a pulse to the clock's stepper motor or by generating a double step.

For example, when DST starts, the software simply adds 3600 seconds (one hour) to the desired position and the clock will then automatically 'fast forward' until it is an hour ahead.

When it is time to synchronise (ie, once every 44 hours), rather than going back to sleep after handling the interrupt, the micro switches on power to the boost regulator which provides either 3.3V or 5V to the GPS module. This is derived from the 2-3V battery voltage.

Once the GPS module has acquired enough satellites to get an accurate time reading, the microcontroller extracts this from the serial data stream and converts it into an internal representation (seconds since 1 January, 2000), applies the time zone offset, calculates if DST applies, calculates the internal crystal oscillator error, and so on – all the steps necessary to keep the clock showing the right time.

When it has finished and the current time setting is confirmed as correct, the GPS module is powered down and the unit goes back to normal operation.

The GPS module

We normally use a GPS module to find our position on the globe. However, the GPS system is based on time signals derived from extremely accurate atomic clocks, so the UTC time is also supplied in the GPS receiver output.

In fact, most time standard bodies around the world use the GPS system as a 'standard beacon' to transfer accurate clock readings between each other. And let's face it, at £20, a GPS module is a tad cheaper than an atomic clock – even a used one!

Most GPS modules follow the NMEA (National Marine Electronics Association) standard for data output and generate a serial data stream at 4800 or 9600 baud, with eight bits per character. They generally use a TTL-level version of the RS-232 serial protocol.

The NMEA standard also describes the content of the data and we use the RMC (Recommended Minimum data) message, which is part of the default output for almost every GPS module made.

You don't have to use the VK2828U7G5LF module; any GPS module which can run off 3.3V or 5V and supply a TTL-level RS-232 stream at 9600 baud should work.

But keep in mind that if its sensitivity is inferior to the VK2828's, or the current drain is higher, your clock might not work as well as our prototype.

Stepping or sweep hands?

Believe it or not, some people actually like the 'tick, tick, tick' sound of stepped clocks and find them soothing and conducive to sleep.

Others may find that noise terribly annoying. So it's really up to you; just keep in mind that if you choose a clock with continuous sweep hands, you will be changing the battery more often.

Also note that if you are using a clock with sweep hands, the DST adjustment cannot take place automatically and you will also need to do a bit of extra work whenever you insert fresh cells (see below for details).

While it's quite hard to find clocks with a battery-powered continuous sweep movement, the movements are readily available on eBay and Ali Express for just a few dollars.

So if you want a sweep hand clock, we suggest you purchase a clock based on its appearance, then replace its mechanism. You can do that at the same time as fitting the GPS timekeeping module. Just make sure to purchase a movement with the correct shaft diameter and length.

Basically, once you have your clock, take the hands off the shaft and then remove the movement from the clock. Measure the shaft diameter and length and find a sweep movement with an equivalent shaft.

The replacement movements are often advertised along with shaft dimensional diagrams so you can match them to your clock. A good place to look is **aliexpress.com** – search for 'JL6262' and you'll find mechanisms for under a fiver (including delivery).

Many of the movements are also supplied with hands, so you can decide whether to keep the hands that came with your clock or replace them with the new ones.

If you want to try to purchase a clock with sweep hands, then the search terms that are worth using in conjunction with 'clock' are: 'sweep', 'continuous sweep', 'silent' and 'mute'.

By the way, if you have a clock with a failed movement but you prefer a stepping second hand, Ali Express and eBay are also an excellent source of low-cost replacement stepping movements, so you can keep your favourite clock in operation almost indefinitely.

Note that the circuit is exactly the same for driving either type of movement, the only difference is in the

firmware; you simply program the chip with the firmware appropriate to the type of movement you are using.

Sweep hand driving limitations

Because the motor on a clock with a continuous sweep second hand needs to be driven constantly, rather than just delivering the occasional pulse, and since the motor is designed to operate at a certain speed, it can only really be sped up or slowed down by around 6%. This is perfectly fine for making one or two second adjustments to keep the clock accurate, but it would take too long to make up an hour during DST transitions.

As a result, if you want automatic DST adjustments, you need to use a clock movement with a stepping second hand.

Having said that, manual DST adjustments on a clock with sweep hands is not that difficult; you let the clock continue to operate, driving the second hand, and wind the minute/hour hands backward or forward by an hour (or whatever the appropriate time period is) and ensure that the minute hand agrees with the position of the second hand as it sweeps around. This is much easier than having to find an accurate time source to completely reset the clock.

Also, when using a clock with a stepping hand and inserting a fresh pair of cells, you simply set the hands to the 12 o'clock position and the clock will then advance the hands to the correct time. This is not possible for the same reason as stated above, so with a clock with a sweep second hand, what you do is set the time to the next half hour (eg, if it's 11:18, set it to 11:30) and it will then wait until the hands are in the correct position before driving the movement.

Circuit description

The full circuit is shown in Fig.7 and the key component is IC1, the PIC16LF88 microcontroller. This drives the clock's stepper motor, controls the power to the GPS module and interprets the output of the module.

Note that the LF version of the PIC16F88 is guaranteed to operate down to 2V, while the standard version is only rated to work down to 4V. Having said that, you may well find that a standard PIC16F88 will operate without fault to below 2V; it just isn't guaranteed.

The 10kΩ resistor and 470µF capacitor connected to pin 4 of IC1 (via a 1kΩ current-limiting resistor) serve to hold the microcontroller in reset for a few seconds after the battery is connected. This provides enough time for you to properly seat the cells in the holder before the microcontroller starts executing its program.

Diode D1 prevents the capacitor from discharging into the microcontroller when the cells are removed.

The serial interface connector CON2 is linked to the microcontroller via a few protective resistors. This design relies on the fact that nearly all modern serial RS-232 interfaces use a threshold of about 1.5V between a high and low signal. This is not what the full RS-232 standard specifies, but we use this fact to provide a simple interface to a personal computer for configuring the clock.

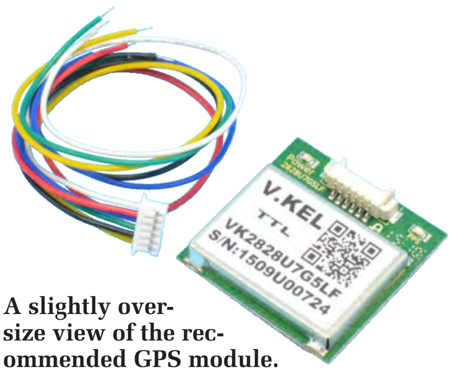
You can use a PICAXE-style serial cable terminated with a 3.5mm stereo jack plug to connect to CON2.

We think most constructors will lack such a cable, so we've provided a mounting location on the board for a low-cost CP2102-based USB/serial converter which has an onboard micro-USB socket. This connects to the serial transmit/receive pins on IC1 (via the same resistor network) and also to GND. Since there is no power connection, you still need the battery in place to set the unit up.

Crystal X1 provides a stable timebase for the clock with the two 22pF capacitors providing the correct loading. Normally, you would need to trim at least one of these capacitors for the clock to be accurate, but since the software automatically corrects for crystal timekeeping errors by periodically comparing the internal (RTC) time to the GPS time, this is not required.

The microcontroller applies power to the GPS module by pulling its pin 3 low. This turns on PNP transistor Q2, which switches on and charges the 220µF capacitor at its emitter to around 2.8V, powering the boost regulator.

This is based around REG1, the MAX756 DC-DC converter. REG1 operates by drawing a current through inductor L1 and then suddenly cutting it off. The collapsing magnetic field causes a positive voltage spike across the inductor that is dumped via schottky diode D2 into the 220µF output capacitor, powering the GPS module.



A slightly oversize view of the recommended GPS module. Other modules should work, but we know this one will!

REG1 can operate with a low supply voltage (down to at least 1.8V) and still deliver a closely regulated output of 3.3V or 5.0V. The actual output voltage is controlled by pin 2 and this can be configured using JP1, to suit the GPS module in use.

L1 must have a saturation current rating of 1A or greater. This means that it should be wound with heavy gauge wire on a powdered iron core; an RF choke will not work. The parts list provides two alternatives. Also, both the 220µF capacitors must have low ESR (equivalent series resistance).

The configuration of Q2 is one of the improvements we've made to the circuit; the original design used a Darlington pair which caused a voltage drop of around 0.7-0.8V from the battery to REG1. This reduced its efficiency markedly and caused it to draw more current from the battery, draining it faster.

With a single transistor and a higher base drive current of 4.5-10mA (due to the 270Ω base resistor), Q2 is capable of supplying at least 400mA – more than enough for REG1 to start up and operate, with an overall efficiency improvement of between 29% (at 3V) and 65% (at 2V).

REG1 generates an internal reference voltage of 1.25V which is used in regulating its output voltage. This reference voltage is also made available at pin 3 of the chip and we pass it back to the microcontroller which uses it as a reference to measure the battery voltage. By accurately measuring the battery voltage, we can stop the clock at the 12 o'clock position before the battery gets too low to operate the microcontroller.

Incidentally, the microcontroller is programmed to measure the battery voltage at the time of greatest current draw (about 160mA) when the GPS module is starting up. If you measure the battery voltage without a load, you will probably get a higher reading.

The GPS module is one of the simpler parts of the circuit. It has two connections for power, two for communications to the microcontroller (transmit and receive data) and an enable signal. We connect the enable line to its V+ pin so that the module is always enabled when power is applied.

As we do not send anything to the GPS module (the manufacturer's default configuration suits us just fine), the receive data line is also pulled high, by a 1kΩ resistor. The 10kΩ resistor in series with pins 8 and 10 of the microcontroller limits

the current into the microcontroller when the GPS module operates at a higher voltage.

The microcontroller drives the clock stepper motor from pins 15, 17 and 18, which are paralleled for a higher output current. When these pins are at a high impedance, no current flows through the clock motor. If they are driven high, there is about +1.5V across CON1, while if they are driven low, there is about –1.5V. The micro produces alternate high and low pulses to drive the motor, at 1Hz for stepping second hand clocks and 8Hz for sweep hand clocks.

Schottky diodes D3 and D4 clamp inductive spikes from the motor windings to the supply rails. These occur when output pins 15, 17 and 18 switch to a high impedance after delivering a pulse to the motor windings and are caused by back-EMF from the collapsing magnetic field of said windings (see Fig.6).

Finally, pushbutton S1 can be held down during start-up to signal microcontroller IC1 to go into configuration mode, where its settings can be changed over the serial/USB interface. LED1 flashes at start-up and indicates whether the clock is in set-up mode or operating normally. The USB module has on-board LEDs to indicate when it has power (red) and if it has a GPS signal (green).

Construction

All of the components for the *GPS-Synchronised Analog Clock* driver, including the GPS module and the AA cell holders, are mounted on a PCB measuring 140 × 61.5mm and coded 04202171. This board is available from the *EPE PCB Service*. The component overlay is shown in Fig.8.

Start by fitting the wire link next to Q2, then follow with diode D1 and the resistors. Check each resistor value with a multimeter before soldering it in place. Follow with D2-D4, being careful to orient all diodes in the same direction as shown in Fig.8.

Next, fit the socket for IC1 (notch at top), switch S1 and REG1. REG1 should be soldered directly to the board and be careful to orient it as shown.

Now solder the ceramic and MKT capacitors in place, followed by the electrolytic capacitors, with their positive (longer) leads through the pads marked '+' on the diagram. Fit Q2, followed by the pin header for JP1 and then LED1, which can be pushed right down or soldered with short leads. Its longer (anode) lead must go through the hole marked 'A'.

Push CON2's pins through the slots in the board and make sure it is flat on the board and its edge is parallel with the edge of the PCB before soldering all five in place. Install CON1 at the same time.

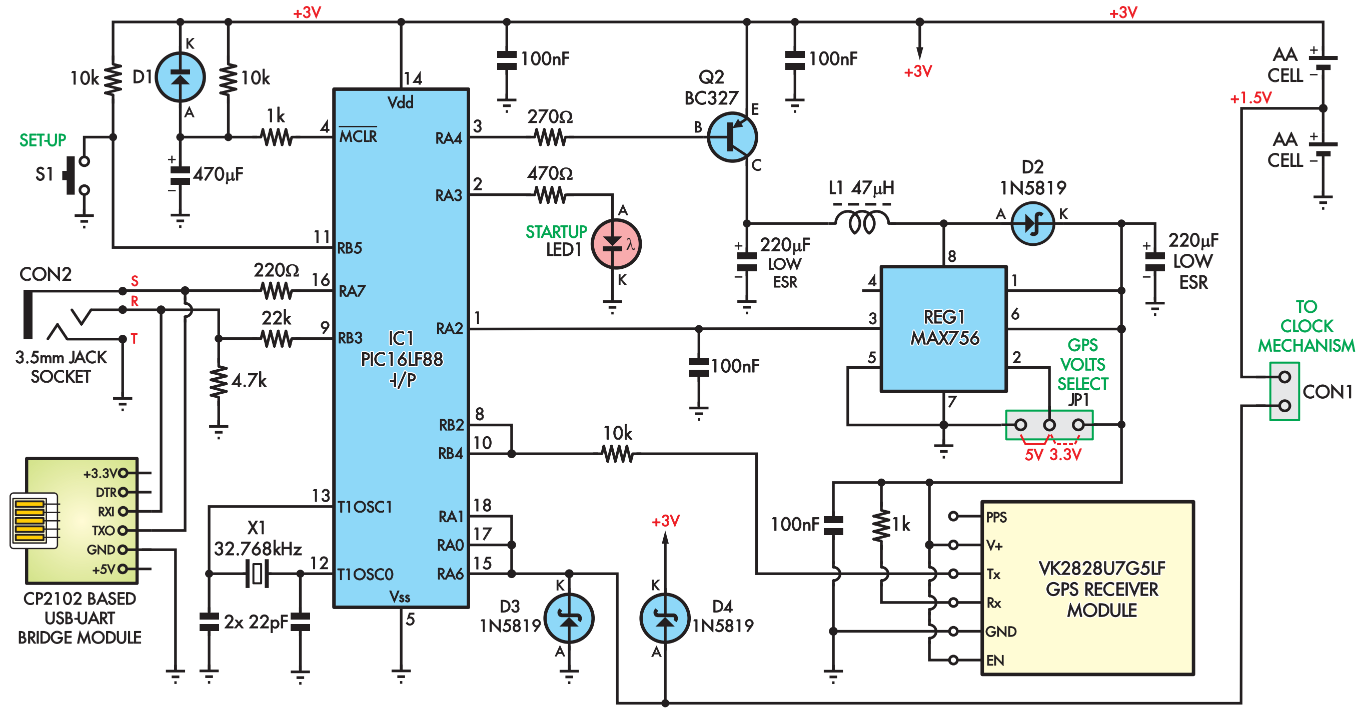
Now use double-sided tape to attach the two cell holders and the GPS module to the board. This is important because it prevents the solder joints from breaking when you insert and remove cells. Solder and trim the cell holder leads. Be careful when soldering them as the plastic can easily be melted if you apply too much heat.

You can now strip the ends of the wire supplied with the GPS module and solder them to the pads with colour coding as shown in Fig.8, then plug the connector into the GPS module socket.

Loop a cable tie through the central hole of toroidal inductor L1 and down through the hole on the board, up through the other hole and tighten it, with the square plastic part on top of the board (so it doesn't stop it from sitting with the bottom side flat against the back of the clock later). Once L1 is held firmly in place on the PCB, solder and trim its two leads.

The PIC16LF88 (IC1) must be programmed using the file coded 0420217A.hex (for a stepping second hand) or 0430217A.hex (for a sweep second hand), both of which can be downloaded from the *EPE* website.

Alternatively, you can purchase a pre-programmed microcontroller. Either way, once it has been programmed, straighten its pins and plug it into the socket with its notched end aligned



GPS SYNCHRONISED CLOCK

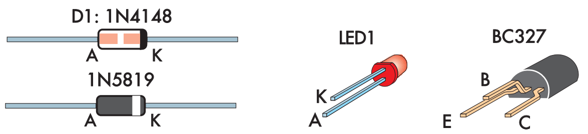


Fig.7: complete circuit for the *GPS Analogue Clock Driver*, omitting only the clock movement which connects to CON1. Microcontroller IC1 powers up the GPS module via transistor Q2 and boost regulator REG1, and receives its serial data stream at pins 8 and 10. When the GPS module is not powered, it uses its internal Real-Time Clock and watch crystal X1 to keep time and produce the pulses from output pins 15, 17 and 18 to drive the clock mechanism. Note that there is no Q1 due to a late circuit update.

Parts list – GPS- Synchronised Clock Driver

1 PCB available from the *EPE PCB Service*, coded 04202171, 140 × 61.5mm
1 VK2828U7G5LF GPS module*
1 CP2102-based USB/serial interface module with microUSB socket#
1 32768Hz crystal (X1)
1 47µH 1A+ inductor
1 small cable tie
1 3.5mm switched stereo socket (CON2)
1 vertical PCB-mount tactile momentary pushbutton switch (S1)
2 single AA PCB-mounting cell holders (Altronics S5029)
1 18-pin DIL IC socket
1 3-way pin header, 2.54mm pitch, plus shorting block (JP1)
1 2-way polarised right-angle PCB-mount header, 2.54mm pitch (CON1)
1 2-way polarised header plug, 2.54mm pitch
1 short length light duty twin lead
1 short length tinned copper wire or component lead off-cut
2 AA alkaline cells

Semiconductors
1 PIC16LF88-I/P microcontroller programmed with either 04120217A.hex (stepping movement) or 04130217A.hex (sweep movement) (IC1) #
1 MAX756CPA DC-DC Converter (REG1; element14 1290853, RS 786-1287)
1 BC327 PNP transistor (Q2)
1 1N4148 diode (D1)
3 1N5819 schottky diodes (D2-D4)
1 3mm high-brightness LED (LED1)

Capacitors
1 470µF 10V electrolytic
2 220µF 25V low-ESR electrolytic (Jaycar RE6324, Altronics R6144)
4 100nF 50V MKT, ceramic or multi-layer ceramic
2 22pF ceramic

Resistors (all 0.25W, 5%)

1 22kΩ	3 10kΩ	1 4.7kΩ
2 1kΩ	1 470Ω	1 270Ω
1 220Ω		

* this module suits the PCB pattern and also has an integral antenna. Other modules can be used but they may have different pin-outs and cable arrangements and some may require an external antenna.

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with the socket (ie, towards the top of the board).

Finally, place a jumper on header JP1. We recommend using the 3.3V setting with the specified module; although this is the minimum specified operating voltage for the VK2828U7G5LF, it will reduce the power consumption while the GPS is active by around 35% and should not affect performance. If you have trouble getting it to work, you can switch to 5V later. If you're using a different GPS module, check its data sheet to see what supply voltage it needs before fitting the shunt. If you leave it off, it could damage the GPS module.

Powering up

At this point, temporarily unplug the GPS module so that you can make some tests. With IC1 in its socket, insert two fresh cells in the battery holder. After a second, you should see one flash from the Startup LED (LED1), followed by a further two flashes another second or so later. These indicate that the microcontroller and the DC-DC converter, respectively, are working. If you do not get these indications, refer to the section below on troubleshooting.

After the double flash, the microcontroller will wait for two minutes, expecting some data from the GPS module before shutting down the DC-DC converter. In this time, you need to measure the voltage at the connector to the GPS module. Ours measured 3.33V and you should get a similar reading. If it's below 3.3V, consider removing a cell and changing to the 5V setting. If you do, it's a good idea to re-measure the voltage to ensure it's correct.

Now that you have confirmed that you will not blow up your GPS module you can remove a cell and plug in the GPS module. Finally, replace the cell and the controller should go through the whole startup sequence as described in the section on troubleshooting.

Modifying the clock mechanism

Now it's time to connect the driver to the clock movement, which involves removing the existing quartz-crystal-based drive circuit and replacing it with a cable to go to the new driver board. Start by removing the cover from the clock mechanism. Identify the leads to the stepper motor coil, cut these, strip them and solder them to a twin-core lead terminated with a 2-way header plug. Insulate the solder joints and anchor the cable (eg, using some silicone sealant) before replacing the cover.

The stepper motor coil should be easily identified, as it will be a large coil of enamelled copper wire. Every clock is different, so you will be on a journey of discovery here.

You can check your modification by using a 1.5V alkaline cell. Just connect the cell to the wires leading to the stepper motor coil, then reverse the cell and repeat. On each connection, the clock's second hand should step by one second (for a stepping clock) or 1/16th of a second (for a clock with sweep hands).

The method of attaching the driver PCB to your clock will also vary, but in the simplest case you can use double-sided adhesive tape to hold it onto the back of the clock.

Troubleshooting

Hopefully, your clock will work first time, but if it does not, you can use the Startup LED (LED1) to help isolate the problem. This LED will flash during normal initialisation (when the set-up button is not pressed) to indicate that each step of the initialisation has been completed. The point at which it does not flash will indicate where you should start hunting. When you insert the battery, you should see the following signals in sequence:

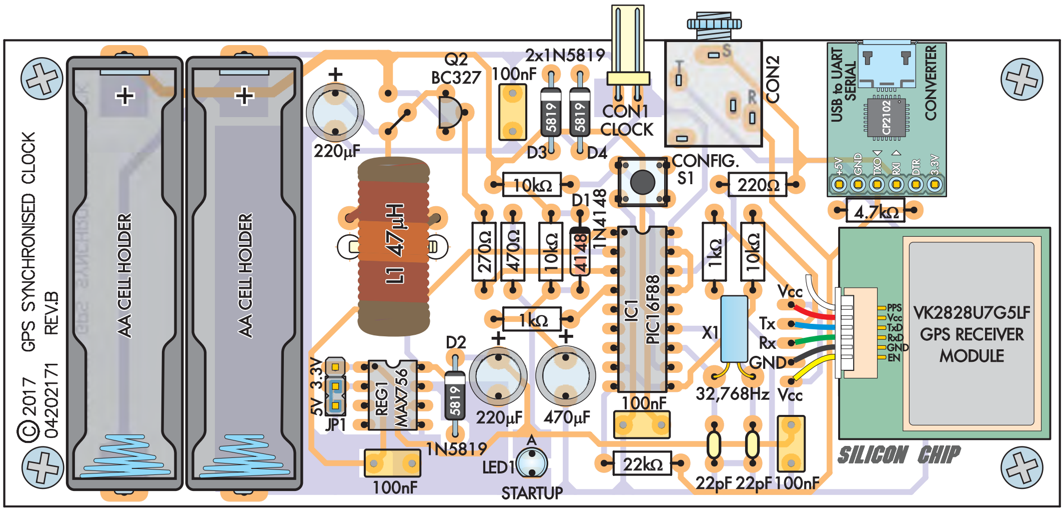
- **One flash:** the microcontroller has started up. If you do not get this then something is fundamentally wrong with the microcontroller or the cells.

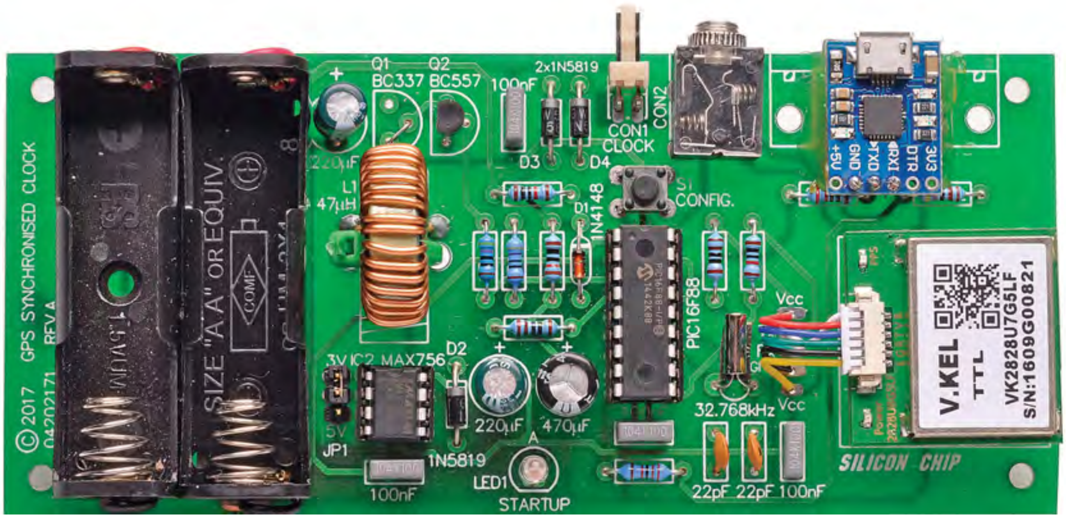
- **Two flashes:** the MAX756 DC-DC converter has started up (determined by measuring a voltage on pin 3 of REG1 via pin 1 of IC1). If you fail to get this signal, check REG1 and its associated components. Check for about 2.7V (with fresh cells) on the collector of Q2 and between 1.23V and 1.27V on pin 3 of REG1.

- **Three flashes:** the GPS module is working and has transmitted its startup message. If you do not get this then check the wiring to the module and that the GPS power supply is between 3.3V and 5.5V. If you have an oscilloscope, check that there is less than 150mV peak-to-peak noise superimposed on the supply rail to the GPS module.

Fig.8: follow this PCB overlay diagram and the same-size photograph below* to build the *GPS Analogue Clock Driver*. Use a socket for IC1 but not REG1. If you use the specified GPS receiver, it will be supplied with a cable colour coded as shown here. Otherwise, you will need to determine the module's pinout from its data sheet and match it up to the labels on the PCB. If it has an enable input, it should normally be tied high (ie, to VCC) for normal operation but check the data sheet to make sure.

*Note that this photo is of the prototype – there is no Q1 (it has been bridged out with a link) and Q2 is now a BC327 (not a BC557), as shown in the overlay diagram above.





- **Four flashes:** the GPS module has locked on to sufficient satellites and has responded with an accurate time signal. This can take up to 90 seconds or more, so be patient. If you don't get this, try putting the board closer to a window and open any metal blinds. If your indoor GPS signal is poor, you will need to keep this in mind when choosing a location for the clock.

Immediately following the GPS lock (four flashes), the clock should double-step around the dial to reach the correct time (assuming a stepped second hand.

If this does not happen, it means that the crystal oscillator (X1) is not working or the clock's stepper motor is not correctly wired to the controller. In particular, check that you have isolated the clock's electronic module and soldered your wires properly to the stepper motor coil. See the 'Setting it up' section below for more information on how to check the connection to the clock motor.

Testing the clock drive

For stepping clock mechanisms, the most important test is that the drive pulse is long enough to reliably step the clock with a supply as low as 2V. If you have a bench supply, you can use clip leads to connect its negative output to the spring in the right-hand cell holder and its positive output to the cathode of D4. You will also need to wire a 47Ω resistor across each cell holder, to provide the 'centre tap' voltage to drive the clock mechanism.

If you don't have a suitable supply, you will just need to scrounge up some almost-but-not-quite-completely-dead AA cells that produce close to 1V each under a moderate load.

Either way, you just need to leave the clock running for a few minutes and check that it doesn't miss any steps. If it does, use the set-up menu (explained below) to increase the pulse width by 8ms and try again. Repeat if necessary, until it works reliably.

Another point to note is that you must sit the clock upright in its normal position while testing. The clock's motor has very little power and if it is going to misbehave, it will occur while the clock is trying to push the second hand up against gravity.

Sweep movements need to be tested more thoroughly and the firmware has a function in the setup menu that makes this quite easy. It will run the clock for an exact number of minutes and then stop. A good test is for 60 minutes and the idea is that the minute and second hands should return to exactly the same spot as they started from. Any error, even by half a second, will indicate a problem.

Once again, you should run this test with a 2V supply, if at all possible, as explained above. It is at that low voltage point that problems will surface if they are going to.

As with the step movement, orient the clock vertically during testing. If the clock does lose some time, the answer again is to increase the pulse width in the set-up menu. This allows the pulse width to be varied in steps of one millisecond with increasing values delivering more energy to the clock's motor at the cost of battery life.

Note that you need to start the test at a normal voltage (about 3V) because the serial interface will not work at low voltages and the clock will not start running at low voltages. Once the test has started running, you can reduce the supply voltage. If you don't have a variable supply, this may be possible to arrange by initially paralleling fresh

Calculating battery life

With an application such as this, battery life is important. After all, what is the point of a clock that does not need adjustment if you are forever changing the batteries? To calculate the consumption, we need to divide the activity of the circuit into phases according to the current drawn from the battery.

Then, for each phase, we determine the current consumption and its duty cycle (the percentage of time that the current is drawn). Finally, we can calculate the average current drawn per hour and then the battery lifetime for a given battery capacity. The tables below are the results for our prototype.

These tables indicate what is the major power user and this is the current drawn while driving the clock's stepper motor. This is where you should concentrate your efforts if you wish to improve the battery life. One way to do this is to reduce the width of the pulse using the set-up menu, but you have to be careful doing this because you may cause the clock to become inaccurate at lower battery voltages.

If you plan to experiment with this, you should connect a variable power supply (with simulated centre tap) in place of the battery and test that your clock steps correctly at less than 2V, the minimum expected battery voltage. Don't just test it on its back either; stand the clock upright in its normal position as you might find that the stepper motor does not have enough power to lift the second hand against gravity.

Power consumption for clocks with stepping hands

Function	Current drain (mA)	On time (seconds)	Total time (seconds)	Duty cycle	Consumption (mAh)
PIC in sleep	0.004	158355	158400	99.97%	0.004
Clock step pulse	3	0.04	1	4.00%	0.120
During GPS sync	80	45	158400	0.03%	0.023
Battery self discharge*	0.009	1	1	100%	0.009
Total					0.158

Expected lifetime for alkaline AA cells (capacity of 2400mAh) in months: 21

Power consumption for clocks with sweep hands

Function	Current drain (mA)	On time (seconds)	Total time (seconds)	Duty cycle	Consumption (mAh)
PIC in sleep	0.004	79200	158400	50%	0.002
Clock step pulse	0.6	0.5	1	50%	0.300
During GPS sync	80	45	158400	0.03%	0.023
Battery self discharge*	0.009	1	1	100%	0.009
Total					0.334

Expected lifetime for alkaline AA cells (capacity of 2400mAh) in months: 10

cells with the slightly flat cells, then disconnecting them later to more thoroughly test the arrangement.

Setting it up

The set-up menu varies depending on which firmware you have installed. That's because the sweep hands firmware does not support DST changes, so the related options have been eliminated. The menu for clocks with step hands is shown in Fig.9 and for sweep hands, in Fig.10.

For clocks with stepping hands, by default the controller is configured for Australia in the NSW, Victorian and Tasmanian time zone and DST rules. If you live in these states and the government has not changed the DST rules since January 2017, then you do not need to do anything.

If you live elsewhere, you will need to change the settings by connecting the *GPS Analogue Clock Driver* to a

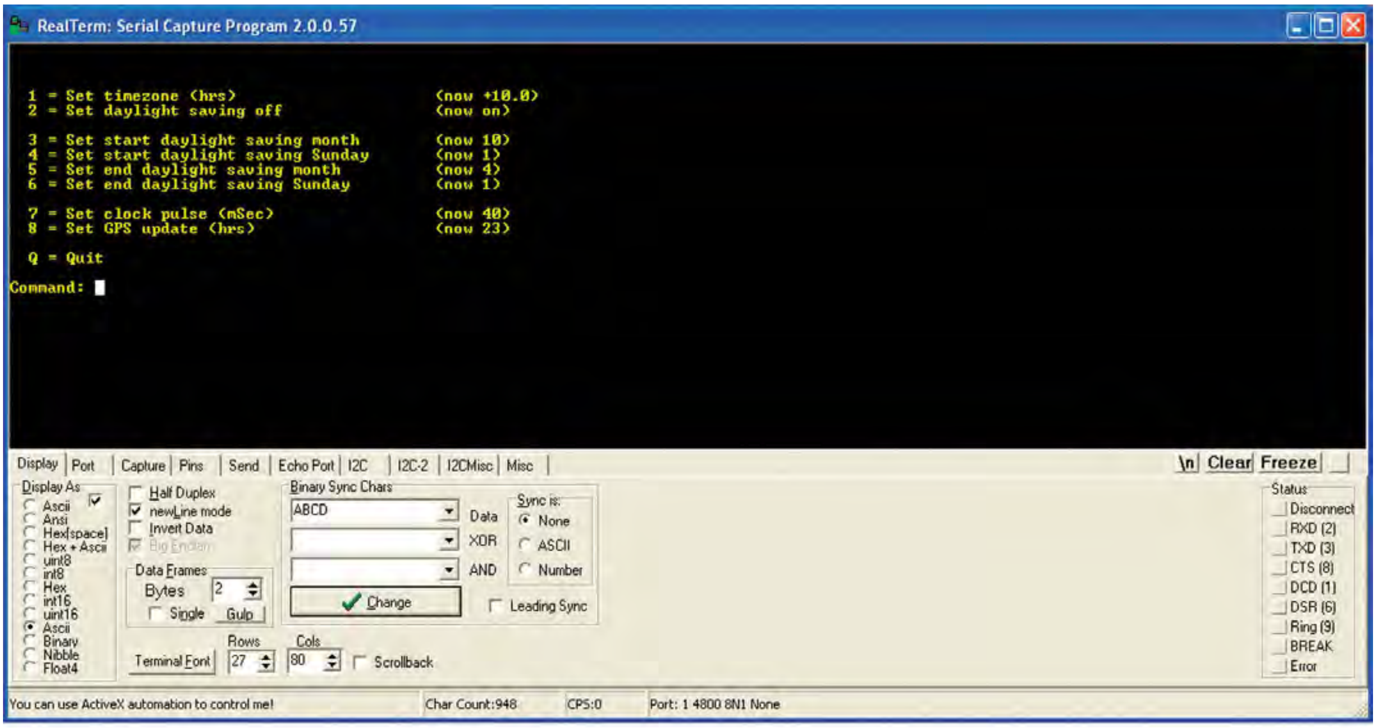


Fig.9: connect the unit to your PC using a microUSB to USB cable, configure a terminal emulator, hold down switch S1 and insert a pair of fresh AA cells to access the configuration menu. The one shown here is for clocks with a stepping second hand. Changing settings is fairly self-explanatory once you've established serial communications.

USB port on your PC via the onboard adaptor. Or if you have a PICAXE programming cable, you can connect this to CON2 instead.

You will also need a serial terminal emulation program running on your computer configured for 9600 baud, 8 data bits, no parity and one stop bit. Many free programs are available on the Internet, including TeraTerm Pro, PuTTY, RealTerm or Hercules Terminal Emulator. Use Google to search for one or more of these names.

To enter set-up mode, hold down the Set-up button (S1) while you install fresh cells and continue to hold it down until you see the menu via the terminal emulator on your PC. The Startup LED (LED1) will also flash when the microcontroller transmits a character to your computer, and this may help in diagnosing communication problems.

If your loction observes DST, you can select any month (1-12) for the end and start. You can also set the day for the event (1st, 2nd, 3rd or last Sunday in the month). The time of the day that DST starts (2am) is fixed in the program, as is the end time (3am).

For either type of clock, the clock pulse width can be changed in steps of 1ms and this setting might need to be adjusted to suit your clock.

Most clocks work with the default setting, but some may need slightly longer pulses to reliably step with a low battery voltage. Also, to gain a little extra accuracy or improve battery life, you can change the interval between GPS synchronisations.

All changes are saved in non-volatile memory and therefore will be retained, even when you remove the battery.

Setting the time

We explained this earlier, but you may not remember the details, so here's a quick run-down.

For clocks with stepping hands, simply set it so that all the hands point at the 12 o'clock position and insert the cells. Once the GPS module has a good signal and IC1 is able to determine the correct time, the hands will 'quick-step' around the dial until the time is correct and then it will run normally.

To save the clock from having to double-step for hours to reach the correct time, it makes sense to power up the clock shortly after 12 o'clock (ie, your local time).

In that way, it will only take about ten minutes or so for the clock to finish double stepping and revert to normal accurate time keeping.

For clocks with sweep hands, it's a bit more tricky. First, check the current time and then set the hour and minute hands so that they are pointing to the immediately following half-hour.

For example, if it's 3:08, set the clock to show 3:30 before inserting the cells. But there's a problem in that the second hand will be pointing at some random position on the dial and when you insert the battery, the clock will sit motionless until it is time to start.

As the time adjustment on most clocks does not affect the second hand you will not have an opportunity to set the second hand to 12 o'clock before the clock starts – and then it is too late.

To solve this, while the clock is waiting for the half-hour to roll around (during which time LED1 flashes slowly), you can press the set-up button (S1) and while you hold this button down, the clock will run, causing the second hand to move around the dial.

When the second hand reaches the exact 12 o'clock position, release S1 and use the normal time setting facility of the clock to adjust the hour and minute hands to the correct position.

Source code

The firmware for this project is written in the C language and can be compiled with either the CCS C compiler or the Hi-Tech C compiler Lite for PIC10/12/16 microcontrollers.

The Hi-Tech C compiler was purchased by Microchip some time ago and is now obsolete, but it can still be downloaded and used. The good thing about it is that it is totally free, so if you want to get into the C language and play around with the code, this is a good way to do it.

Download links and installation instructions are available at: **www.cs.ucr.edu/~eblock/pages/pictools/install.html**

Conclusion

Well, that's it. With your clock properly set up, you can hang it on the wall and be assured that at least one clock in the house is always accurate. Just make sure it has a decent GPS signal where it's located (eg, not deep inside under a corrugated iron roof!) so that it will stay synchronised. (Note that you can also check the clock's accuracy at any time if you have Internet time enabled on your desktop computer.)

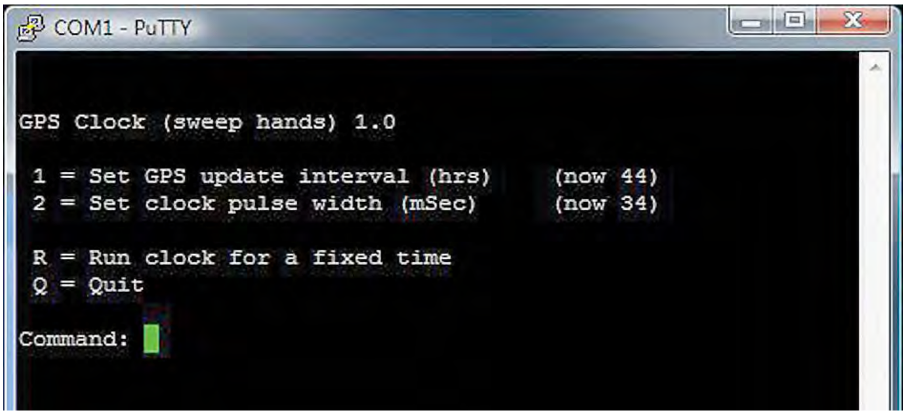
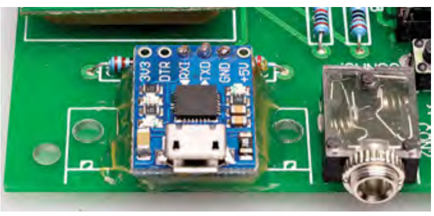


Fig.10: the set-up menu for clocks with sweep hands, shown here, is much simpler than for stepped hands because it does not include any of the DST options. However, it does include the option to run the clock for a fixed time so that you can check that it isn't losing any time. This should ideally be checked with a supply voltage of around 2V (see text).



A close-up of the micro-USB module (left) and the optional 3.5mm programming socket (CON2, right).

Here's how we secured the PCB to the clock – a little bit of judicious filing removed a couple of ridges, then a few dollops of silicone sealant holds the PCB securely in place. This method allows easy battery change later on.

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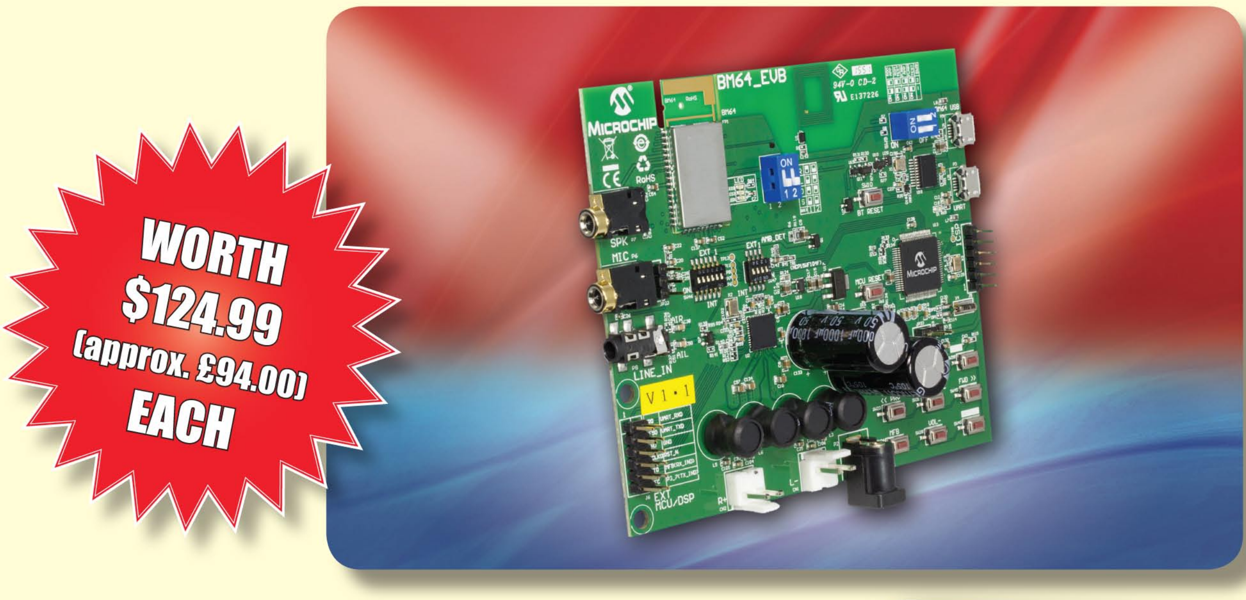

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Build the SC200...

New high performance amplifier module

- 200W into 4Ω
- 0.001% distortion

Part 2 – By NICHOLAS VINEN

Last month, we introduced the *SC200 Amplifier Module*. This month, we're presenting the construction details.

In the first article, we described the circuit of the SC200 audio amplifier, provided a parts list and described the optional clip detection circuitry, which is housed on the same PCB.

This month, we'll go through the construction procedure, which is quite straightforward. It basically involves mounting the smaller components on the PCB, drilling the heatsink, then mounting the power devices on the heatsink and soldering their leads onto the PCB.

Before getting into the construction, there's one minor change in the design since we presented the circuit last month. We found that the best performance is obtained with the main filter inductor, L2, mounted on its side, rather than horizontally on the PCB, as shown in the photos last month. This reduces the interaction between its magnetic field and components on the PCB. Luckily, we designed the PCB with two slots for a cable tie in case we found this to be necessary. So no changes are required to the circuit or board; simply mount the inductor as shown in the photos and diagrams *this* month, rather than flat as shown in the photos last month.

We have also made provision for the SMD resistor which was previously fitted inside the hole in the middle of the bobbin to be mounted on the underside of the board, so it won't interfere with the now vertical inductor. More on that later.

Heatsink selection

The *SC200 Amplifier Module* is built on a double-sided PCB, which is available from the *EPE PCB Service*, coded 01108161 and measuring 117 × 84mm. The seven main power transistors are arranged in a row along the top (back) edge and these are mounted on a diecast aluminium heatsink.

The power figures given last month (135W into 8Ω, 200W into 4Ω) can be obtained with entirely passive cooling (ie, no fans), provided there is sufficient ventilation where the heatsink(s) are mounted.

Having said that, it would be possible to add fan-forced cooling should, but we won't go into details here.

The heatsink used on our prototype and pictured this month measures 150 × 75 × 46mm (Jaycar HH8555) but we used that one primarily because we already had a partially drilled example in our workshop.

We recommend that you use a slightly larger 200 × 75 × 48mm heatsink (Altronics H0536) instead. This will keep the transistors cooler when the amplifier is operating at higher power levels.

There's also a 300mm-wide version of the same heatsink available for only a couple of dollars more (Altronics H0545) and if you have room for it in your chassis, the amplifier will run even cooler. But the following instructions will assume you're using the 200mm type which was specified in the parts list.

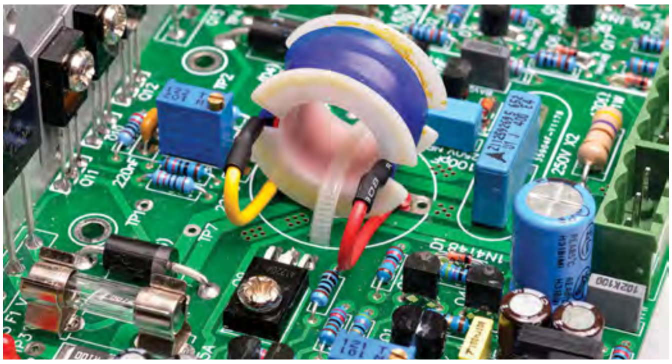
Construction

Start by fitting the smaller components to the PCB. Use the overlay diagram, Fig.4, as a guide. Note the area in the lower right-hand corner with the dotted outline. The components in this area form the optional clip detection circuitry. If you don't need that, you may omit all those components to save time and money.

There are five 3W SMD resistors on the board and it's best to start by soldering them while the PCB will still sit flat on your bench. They are quite large so it's fairly easy to install them, although you will find it even easier if you spread a thin layer of flux paste on each associated pad before you do so. Solder the four 0.1Ω resistors first.

There are pads on either side of the board to which the 6.8Ω 3W resistor can be soldered. As mentioned earlier, we suggest you solder it to the pads on the underside so it does not interfere with the mounting of air-cored inductor L2, later.

In each case, you can clamp the resistor in place over the appropriate pads and then apply solder at each end if



The inductor mounting shown in this close-up is a modification to that shown in the prototype (left) – see text.

you have suitable tools. Otherwise, the simplest method is to apply solder to one of the pads and then heat it with your iron while you slide the resistor in place and allow the solder to flow onto it. You can hold the resistor with a pair of tweezers while doing this.

Once you've removed the heat, make sure it can't move before soldering the opposite end, then add a little fresh solder to the first pad to ensure the joint has formed properly. When finished, it's a good idea to inspect the joints under good light and magnification to ensure they have formed proper fillets.

By the way, we're using SMD 3W resistors since they are a lot more compact than 5W wirewound resistors and also have much tighter tolerances. And even though it is largely of academic interest as far as the circuit performance is concerned, these SMD resistors are non-inductive.

Through-hole components

You can now solder the two small through-hole diodes, D1 and D2. Don't get these mixed up as they may look similar and ensure they have their cathode stripes oriented as shown in Fig.4[a]. If building it with the clip detector, fit diodes D5-D7 now as well.

Follow with all the quarter-watt resistors, using a DMM to check the resistance of each batch before installing them, as the coloured bands can be ambiguous. Don't forget to slip a ferrite bead over one end of the 100Ω resistor near CON1 before soldering it into place.

As stated earlier, you can leave out the nine small resistors in the clip detector circuit if you don't need it. Alternatively, if you are building it with the clip detector, fit zener diodes ZD1 and ZD2 now, with their cathode stripes as shown in the overlay diagram.

Then mount the two 1W resistors, followed by the larger diodes D3 and D4, again referring to Fig.4 for the correct orientation. This is most important as they will short out the amplifier output if reversed! Now attach medium-power transistors Q8 and Q9 using 6mm M3 machine screws and nuts, having bent their leads at right angles to fit through the mounting holes on the PCB. Don't get them mixed up; Q8 must be a KSC2690A (NPN) while Q9 is a KSA1220A (PNP). Only after their mounting screws have been done up tightly, should you solder and trim their leads.

You can now fit the LEDs to the board. In each case, the anode (longer) lead goes in the mounting hole closer to the bottom of the board, with the flat side of the lens (cathode) towards the top. You must fit LED1; LEDs2-5 are optional but highly recommended as they indicate the presence of the two power rails and the state of fuses F1 and F2. LED6 can be fitted if you are building the clip detection circuitry, or you can leave it off and use an off-board LED connected via CON4, which you will solder in place later.

You may fit PCB pins for TP1-TP7 now. Note that there are two positions marked at TP7; they are connected to the same copper trace and are provided merely for convenience, as it's necessary to measure between TP7 and TP3-6, the latter of which are spread across the board. If you have alligator clip leads for your DMM, we recommend fitting PC stakes for one of the TP7 points along with either TP4 or TP5 (whichever is closer) but leaving the others as bare pads, since it's easier to connect to bare pads with standard pointed PCB probes.

Trimpots VR1 and VR2 are next on the list. VR1 must be a 1kΩ multi-turn trimpot and it is installed with its screw towards the centre of the board, as shown. VR2 may be a mini horizontal trimpot; however, we found it quite fiddly to use this type to zero the output offset voltage so we've made provision for a multi-turn trimpot which is a bit more expensive but less sensitive. If using a multi-turn type, mount it with the same orientation as VR1, ie, with the screw towards the bottom of the board.

You can now fit the smaller capacitors. There are six MKT capacitors plus three which can be either ceramic or MKT (or in the case of the 150pF type, MKP). Polarity is not important for any of these. Follow with the small-signal transistors but don't get the different types mixed up. You will likely need to crank the leads out slightly to fit the PCB pads (use small pliers).

Three of the transistors are for the clip detection circuitry and may be omitted; note that one of these three is a 2N5551 high-voltage NPN type. The other seven (Q1-Q7) must be installed. Now you can solder the four M205 fuse clip holders in place. Make sure each is pushed all the way down on the PCB before soldering and that the retaining clip is facing towards the outside of the fuse, otherwise you will not be able to install the fuses later. Note that soldering these parts requires quite a bit of heat as they are on large copper pads.

Now install the electrolytic capacitors. The orientation is important; in each case, the longer (positive) lead should go into the pad closer to the left side of the PCB. If in doubt, refer to the '+' symbols shown in Fig.4. Note that the 47µF capacitor closest to Q5 must have a voltage rating of at least 35V (shown in the overlay diagram) but the others may be rated at 25V.

We used the 150mm-wide Jaycar HH8555 heatsink (left) on our prototype but recommend the larger 200mm Altronics H0563 (right) instead. There's also an even larger (300mm wide) Altronics heatsink available (H0545) if maximum cooling is important.

Now it's time to fit pluggable terminal blocks CON2 and CON3. Make sure you orient these so that the wire entry holes are on the outside. The easiest way to do this is to temporarily attach the plugs, place the sockets on the PCB and then remove the plugs before soldering the sockets. Make sure the socket pins are pushed all the way down before soldering them.

You can now also fit the input connector. There are three possibilities: either a horizontal RCA socket (CON1), vertical RCA socket (CON6) or polarised pin header to go to an off-board socket (CON5). If you wish, you can fit CON1 along with one of the other two, although you will only be able to use one at any given time.

With those in place, fit the 100nF 250V MKP capacitor which goes next to L2. There are a few different mounting holes, to suit capacitors with different pin spacings. Now would also be a good time to mount CON4 for the clip detector circuit, if you are using it with an off-board LED.

Alternative SMD components

We won't go into a lot of detail on this topic as most constructors will probably be happy to build the amplifier using mostly through-hole components, as detailed above.

But since it was easy, we made provision on the PCB for a number of the components to be substituted with SMD equivalents. This includes small-signal transistors Q1-Q7, Q17 and Q18, diodes D1, D2 and D5-D7, zener diodes ZD1 and ZD2, the 1W resistors and the non-electrolytic capacitors.

The main reason for using optional SMD equivalents is primarily cost. It probably isn't worthwhile to go out and buy the optional SMDs for this project, but if you already have them, they would have cost you very little.

The alternative parts are shown in the panel opposite, and the mounting locations are shown in Fig.4(b). Of course, you may choose to substitute some of these parts but not all, depending on what you have on hand.

Most of the parts listed are either direct equivalents to the through-hole versions or have superior performance. They are all mounted in place of the through-hole components, on the top of the board – with two exceptions. One is D3 and D4, which if substituted, are fitted on the underside because there are too many tracks on the top side.

And while Q8 and Q9 are not listed in the parts list, nor shown in (Fig.4[b]), it is possible to substitute these with FZT696B (NPN; Q8) and FZT796A (PNP; Q9). We haven't actually tested it, but there is provision for them on the underside of the PCB (under the through-hole mounting locations) and should work *in theory*.

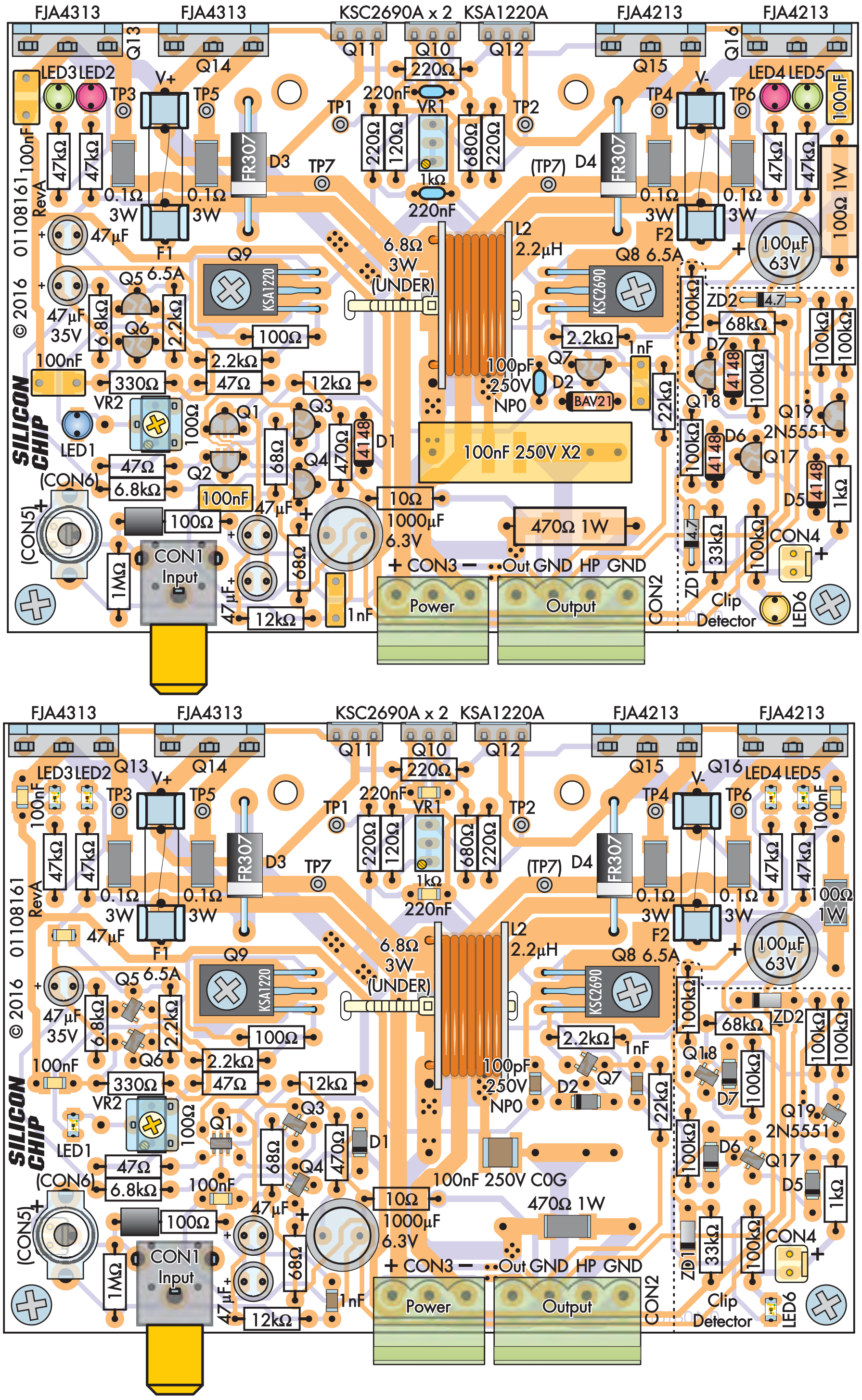


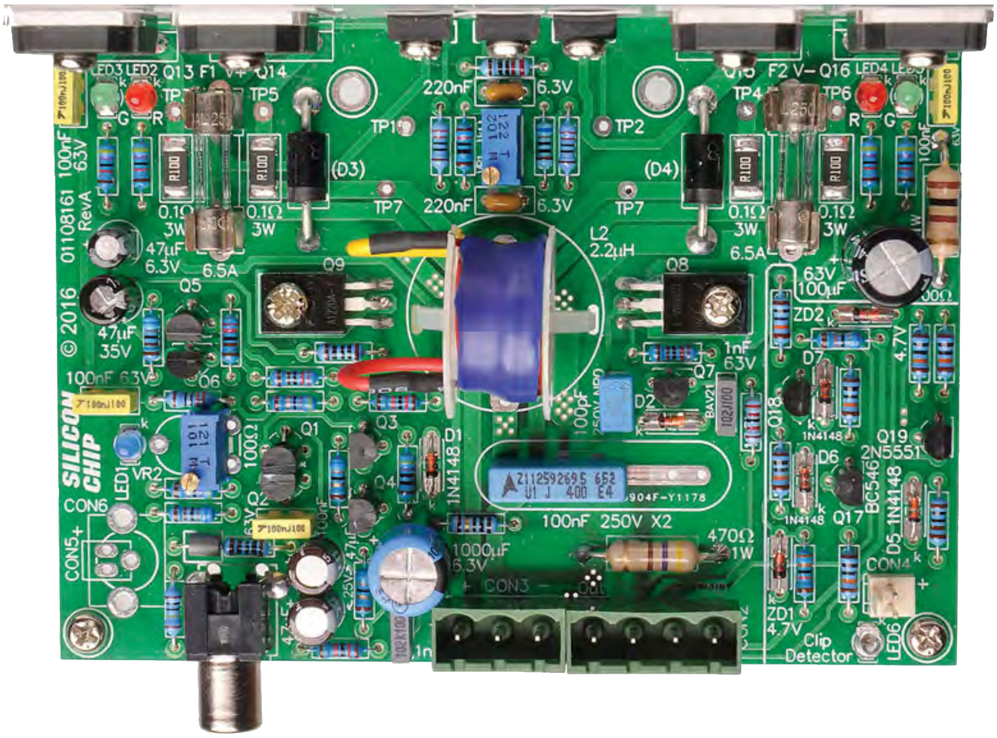
Fig.4: two versions of the PCB component layout (the PCB itself is identical). The top (Fig.4[a]) is for those who don't like SMD components – only five are used and they're all quite large and easy to solder. The alternative (bottom) layout (Fig.4[b]) uses rather more SMDs – mainly semiconductors and capacitors. See the alternative parts list opposite.

Winding inductor L2

This is easiest if you make up a winding jig. See the accompanying panel for details on how to do it. You only need a few cheap and easy-to-obtain items (that you may already have), and it will come in handy any time you need to wind a small air-core choke, so we recommend that you build one if you haven't already.

The inductor is wound using a ~1m length of 1.25mm diameter enamelled copper wire on a 10mm-wide, 13mm-inner diameter plastic former bobbin. Fit the bobbin to the jig, or if you don't have a jig, wind some electrical tape around a bolt or dowel so that it is a firm fit through the centre of the bobbin, to prevent the plastic breaking while winding on the copper wire.

For a neat result, the wire can first be straightened by securing one end in a vice and pulling hard on the other end with a large pair of pliers. This



This completed PCB matches the 'through-hole' version opposite (Fig.4[a]). In the surface-mount version (Fig.4[b]) the SMD components are in the same positions as the through-hole versions above – but watch the polarity!

requires a fair bit of strength so be careful in case the pliers or vice let go. Make a right-angle bend in the wire 25mm from one end, then insert this end through one of the slots in the bobbin and wind on seven close-packed turns, which should fill the width of the bobbin. In case the winding direction affects performance, we recommend that you wind in the same direction as we did, as shown in the photo.

Once that layer is complete, wind another 6.5 turns on top, again close packed and in the same direction, then bend the wire through the opposite slot it started through and cut it off 25mm from the bobbin.

To hold the windings in place, cut a 10mm length of 20mm-diameter heatshrink tubing and slip it over the bobbin, then shrink it down gently using a hot air gun on a low setting. Trim the two protruding wires to exactly 20mm from the base of the bobbin, then strip 5mm of the enamel from each end using either emery paper or a hobby knife/scalpel and tin the leads.

To get the specified performance, you must mount the inductor as shown in Fig.4 and in the photos. Two slots are provided for a cable tie to hold it in place. Bend its leads to fit through the appropriate pad, then fit and tighten the cable tie before soldering and trimming the leads. Note the way we've oriented it; each wire from the PCB runs up and over the top of the bobbin.

Drilling and tapping the heatsink

The mounting locations for the power devices on the heatsink are detailed on the accompanying panel, which incorporates a drilling diagram. As explained in that panel, you have the option of either tapping the seven holes, which is the neatest solution, or offsetting the holes by around 5mm in either direction (left or right, to clear the heatsink fins) and then drilling them all right through the heatsink. You can then attach the power devices using longer (~15mm) machine screws fed between through the fins.

This is the approach we took for the prototype as it's a lot less work, however, you do have to be very accurate in drilling the holes, both in terms of the initial position and in making sure that they are drilled at right angles to the heatsink face. If any of the holes are off by more than about half a millimetre, you will find it between tricky and impossible to fit the nuts to the screw shafts. If you decide to tap the holes instead, while this is more work and requires some patience, the exact hole positions are no longer quite so critical.

After you have drilled and possibly tapped the transistor mounting holes, you will also want to do something about mounting it in the chassis. Our preferred method is to drill and tap three additional holes along the bottom of the heatsink to hold it in place. However, it's also possible to fit right-angle brackets to the fins at either end of the heatsink by drilling right through them and using screws and nuts to hold them in place.

Once all holes have been drilled, deburr them using an over-sized drill bit and clean off any aluminium particles or swarf. Check that the areas around the holes are perfectly smooth to avoid the possibility of puncturing any of the insulating washers.

Final assembly

Now it's time to mate the PCB with the main heatsink but first, re-check the face of the heatsink. All holes must be deburred and it must be perfectly clean and free of any grit or metal swarf.

Start the heatsink assembly by mounting transistors Q10, Q11 and Q12 (see Fig.6). A silicone rubber washer goes between each of these transistors and the heatsink. If you can't get TO-126/TO-225 insulating washers, you can carefully cut down some TO-220 washers to fit the devices. Make sure they're small enough to fit side-by-side on the heatsink but not so small that you risk any contact between the metal pad on the rear of each device and the face of the heatsink.

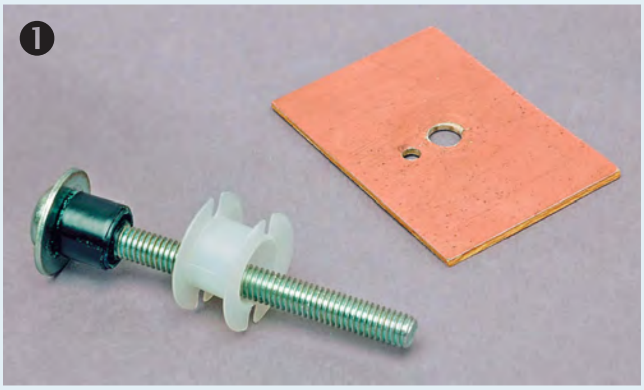
Alternative SMD parts

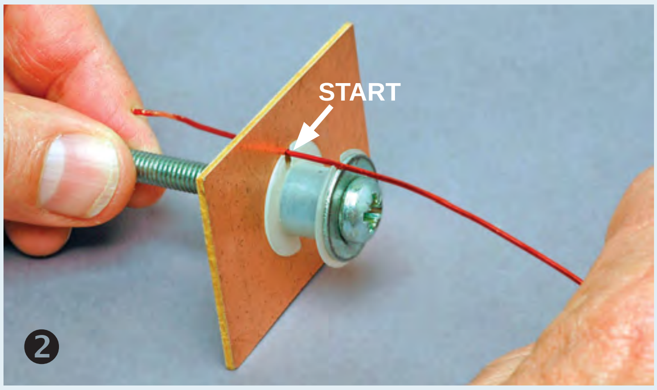
Semiconductors
3 BC846 transistors (Q3,Q4,Q7)
4 BC856 transistors (Q1,Q2,Q5,Q6)
1 blue SMD 3216/1206 LED (LED1)
2 red SMD 3216/1206 LED (LED2,4)
2 green SMD 3216/1206 LED (LED3,5)
1 LL4148 or similar small-signal diode (D1)
1 BAV21W-TP schottky diode (D2)
2 VS-3EJH02 hyperfast rectifiers (D3,D4)

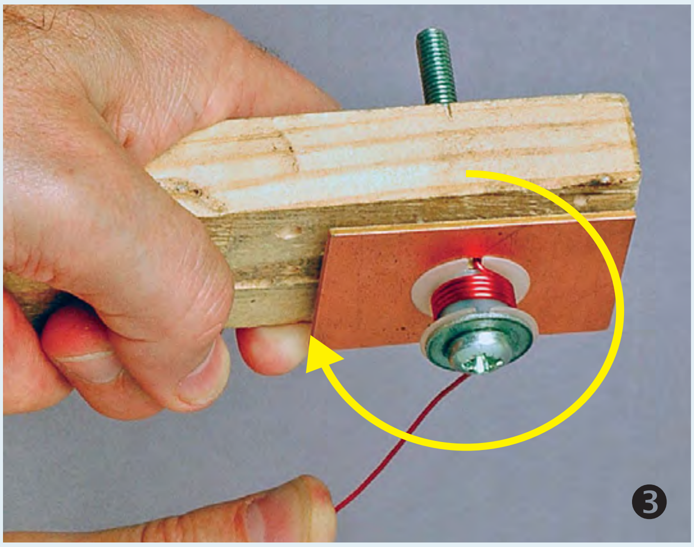
Resistors
1 470Ω 1W 5% SMD 6332/2512
1 100Ω 1W 5% SMD 6332/2512

Capacitors
1 47µF X5R 6.3V SMD ceramic 3216/1206
2 220nF X7R 50V SMD ceramic 3216/1206 or 2012/0805
1 100nF 250V C0G SMD ceramic 5652/2220 or 4532/1812
4 100nF X7R 100V SMD ceramic 3216/1206 or 2012/0805
2 1nF C0G 100V SMD ceramic 3216/1206 or 2012/0805
1 150pF C0G 250V SMD ceramic 3216/1206 or 2012/0805

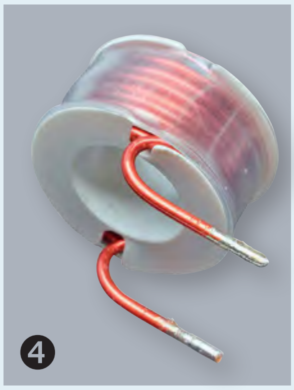
Making a winding jig for the 2.2µH inductor







These photos show how the winding jig is used to make the 2.2µH inductor. First, the bobbin is slipped over the collar on the bolt (1), then an end cheek is attached and the wire threaded through the exit slot (2). The handle is then attached and the coil tightly wound onto the bobbin using 13.5 turns of 1.25mm-diameter enamelled copper wire (3). The finished coil (4) is secured using one or two bands of heatshrink tubing around the outside.



The winding jig consists of an M5 × 70mm bolt, two M5 nuts, an M5 flat washer, a piece of scrap PCB material (approximately 40 x 50mm) and a scrap piece of timber (approximately 140 × 45 × 20mm) for the handle.

In use, the flat washer goes against the head of the bolt, after which a collar is fitted over the bolt to take the bobbin. This collar should have a width that's slightly less than the width (height) of the bobbin and can be wound on using insulation tape.

Wind on sufficient tape so that the bobbin fits snugly over this collar without being too tight.

Next, drill a 5mm hole through the centre of the scrap PCB material, followed by a 1.5mm exit hole about 8mm away that will align with one of the slots in the bobbin. The bobbin can be slipped over the collar, after which the scrap PCB 'end cheek' is slipped over the bolt (ie, the bobbin is sandwiched into position between the washer and the scrap PCB).

Align the bobbin so that one of its slots lines up with the exit hole in the end cheek, then install the first nut and secure it tightly. The handle can then be fitted by drilling a 5mm hole through one end, then slipping it over the bolt and installing the second nut.

If the holes are tapped, these three transistors can be secured using M3 × 10mm machine screws. Alternatively, if you have drilled non-tapped holes, use M3 × 15mm or 20mm machine screws, with the screws coming through from the heatsink side (ie, the screw heads go between the heatsink fins).

Make sure the three transistors and their insulators are properly vertical, then do the screws all the way up but don't tighten them yet; ie, you should still just be able to rotate the transistors.

The next step is to fit an M3 × 9mm (or 10mm) tapped spacer to each of the four mounting holes on the PCB. Secure these using M3 × 6mm machine screws. Once they're on, sit the board down on the spacers and lower the heatsink so that the transistor leads pass through the appropriate holes.

The four output transistors (Q13-Q16) can now be fitted. Two different types are used, so be careful not to mix them up (check the layout diagram). As shown in Fig.6(b), these devices must also be insulated from the heatsink using silicone insulating washers.

Start by fitting Q13. The procedure here is to first push its leads into the PCB mounting holes, then lean the device back and partially feed through its mounting screw with a flat washer. Hang the insulating washer off the end of the screw and then loosely screw the assembly to the heatsink.

The remaining three devices are then installed in exactly the same way but take care to fit the correct transistor type at each location. Once they're in, push the board down so that all four spacers (and the heatsink) are in contact with the benchtop. This automatically adjusts the transistor lead lengths and ensures that the bottom of the board sits 9-10mm above the bottom edge of the heatsink.

Now adjust the PCB assembly horizontally so that the transistor leads are as vertical as possible. If you have tapped the holes, and assuming you're using the specified 200mm-wide heatsink, this will be when each side of the PCB is 41.5mm in from its adjacent heatsink end. Once you are sure it is properly positioned, tighten all the transistor screws just enough so that

Drilling and tapping the aluminium heatsink

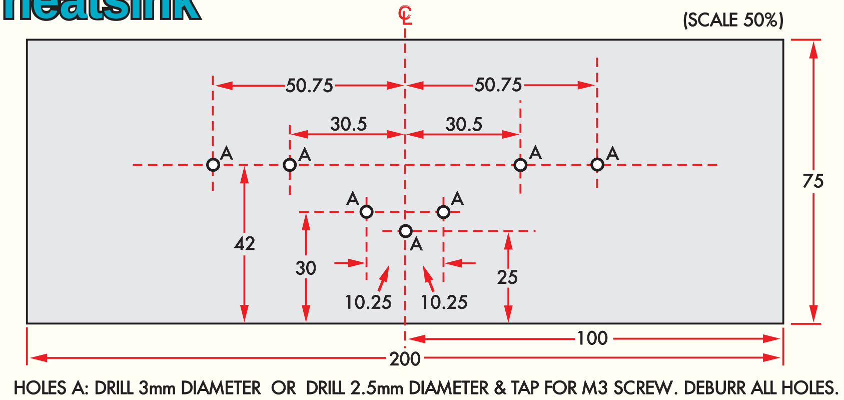


Fig.5: this half-size diagram shows the heatsink drilling details. The holes can either be drilled and tapped (using an M3 tap) or can be drilled to 3mm and the transistors mounted using machine screws, nuts and washers.

Fig.5 above shows the heatsink drilling details. If tapping the holes, they should be drilled to 2.5mm diameter **right through the heatsink plate** and then tapped to 3mm. Alternatively, the holes can be drilled through using a 3mm drill and the transistors mounted using screws, nuts and washers.

It's somewhat more work to tap the holes, but it makes mounting the transistors quite a bit easier (no nuts required) and gives a much neater appearance.

Before drilling the heatsink, you will have to carefully mark out the hole locations using a very sharp pencil. Then use a small hand-drill fitted with a 1mm bit to start the location of each hole. This is important as it will allow you to accurately position the holes (the locations are critical) before stepping up to larger drills in a drill press.

Be sure to use a drill press to drill the holes (there's no way you'll get the holes perfectly perpendicular to the mounting face without one). Use a small pilot drill to begin with (eg, 1.5mm), then carefully step up the drill size to either 2.5mm or 3mm. The holes have to go between the fins so it's vital to accurately position them. In addition, you can drill (and tap) three holes in the base of the heatsink so that it can later be bolted to a chassis.

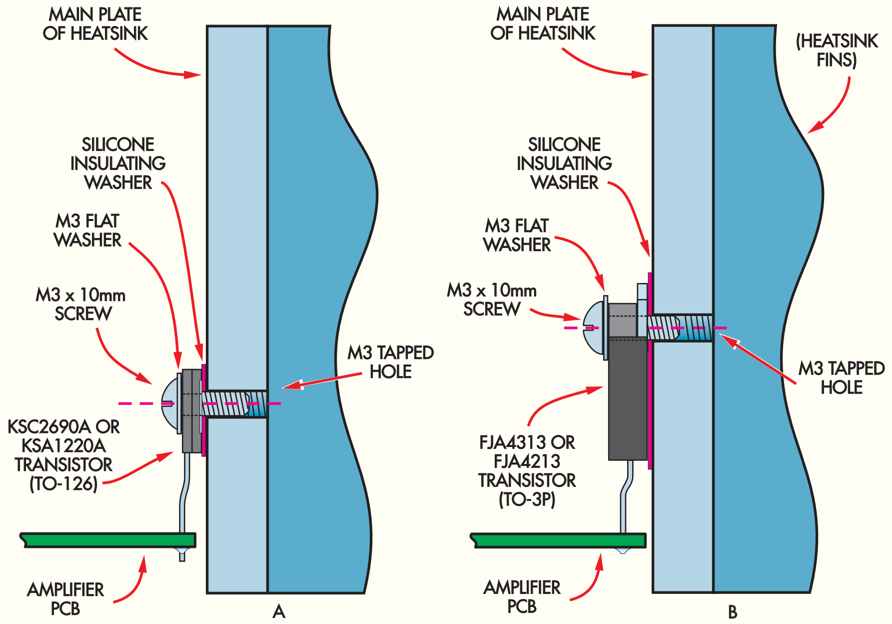


Fig.6: here's how the driver (left) and power (right) transistor are secured to the heatsink. Ensure there is no short between the collectors and heatsink.

Be sure to use a suitable lubricant when drilling the holes. Kerosene is the recommended lubricant for aluminium but we found that light machine oil (eg, Singer or 3-in-1) also works well for jobs like this.

Don't try drilling the holes in one go. When drilling aluminium, it's important to regularly remove the bit from the hole and clear away the metal swarf. If you don't do this, the aluminium swarf has a nasty habit of jamming the drill bit and breaking it. Re-lubricate the hole and the bit with oil each time before you resume drilling.

Tapping

To tap the holes, you need an M3 intermediate (or starting) tap (not a finishing tap). The trick is to take it nice and slowly. Keep the lubricant up and regularly wind the tap out to clear the metal swarf from the hole. Re-lubricate the tap each time before resuming.

Do not at any stage apply undue force to the tap. It's easy to break a tap in half if you are heavy-handed and if the break occurs at or below the heatsink's face, you can scratch both the tap and the heatsink (and about $25). Similarly, if you encounter any resistance when undoing the tap from the heatsink, gently rotate it back and forth and let it cut its way back out. In short, don't force it.

Having completed the tapping, deburr all holes using an oversize drill to remove any metal swarf from the mounting surface. The mounting surface must be perfectly smooth to prevent punch-through of the transistor insulating washers.

Finally, the heatsink should be thoroughly scrubbed cleaned using water and detergent and allowed to dry.

Fig.6 (left) shows the mounting of the amplifier to the heatsink once all the above drilling and tapping is completed.

Note differences between the driver (left) and power (right) transistors. It is imperative that silicone insulating washers are used to isolate the transistors from the heatsinks; you can easily check this with your multimeter on a high 'ohms' range between the collectors and heatsink.

ANY reading will mean there is a problem – sort it out before continuing or the transistor life can be measured in milliseconds when you apply power.

they are held in place while keeping the insulating washers correctly aligned.

The next step is to lightly solder the outside leads of Q13 and Q16 to their pads on the top of the board. The assembly is then turned upside down so that the heatsink transistor leads can be soldered. Before soldering the leads, though, it's important to prop the front edge of the board up so that the PCB is at right-angles to the heatsink. If you don't do this, it will sag under its own weight and will remain in this condition after the leads have been soldered.

A couple of cardboard cylinders cut to 63mm can be used as supports (eg, one at each corner). With these in place, check that the board is correctly centred on the heatsink, then solder all 21 leads. Make sure the joints are good since some can carry many amps at full power.

Once the soldering is completed, trim the leads and remove the two supports near the heatsink, as these are no longer required; the transistors should be mounted to the chassis via the heatsink only, otherwise, thermal cycling could crack their solder joints.

Now turn the board right way up again and tighten the transistor mounting screws to ensure good thermal coupling between the devices and the heatsink. Don't over-tighten the mounting screws, though. Remember that the heatsink is made from aluminium, so you could strip the threads if you are too ham-fisted.

Checking device isolation

You must now check that the transistors are all electrically isolated from the heatsink. That's done by switching your multimeter to a high ohms range and checking for shorts between the heatsink mounting surface and the collectors of the heatsink transistors (note: the collector of each device is connected to its metal face or tab).

For transistors Q11-16, it's simply a matter of checking between each of the fuse clips closest to the heatsink and the heatsink itself (ie, on each side of the amplifier).

That's because the device collectors in each half of the output stage are connected together and run to their respective fuses.

Transistor Q10 (the VBE multiplier) is different. In this case, you have to check for shorts between its centre (collector) lead and the heatsink.

In either case, you should get an open-circuit reading. If you do find a short, undo each transistor mounting screw in turn until the short disappears. It's then simply a matter of locating the cause of the problem and remounting the offending transistor.

Be sure to replace the insulating washer if it has been damaged in any way (eg, punched through).

Power supply

The power supply requirements for this module are optimal with supply rails of ±55-60V, nominally ±57V, from a 45-0-45 transformer. We will present the details next month.

A single 300VA transformer is sufficient to power a stereo amplifier for amplifying normal program material, although it will not allow continuous full power output from both channels simultaneously.

For that, you would need either one transformer rated for at least 500VA, or a separate 300VA transformer and power supply per channel.

For lower-power applications, a 160VA 45-0-45 transformer is available (Altronics M5345A). We wouldn't recommend using this for stereo applications, but it would be suitable for a single channel amplifier if continuous full-power delivery is not required.

If you don't need the full 135W/200W rating, there's also the possibility of using a smaller transformer with lower voltage secondaries, for example, a 160VA 30-0-30 transformer (eg, Altronics M5330A).

Some components would need to be changed; we'll have more details on that next month.

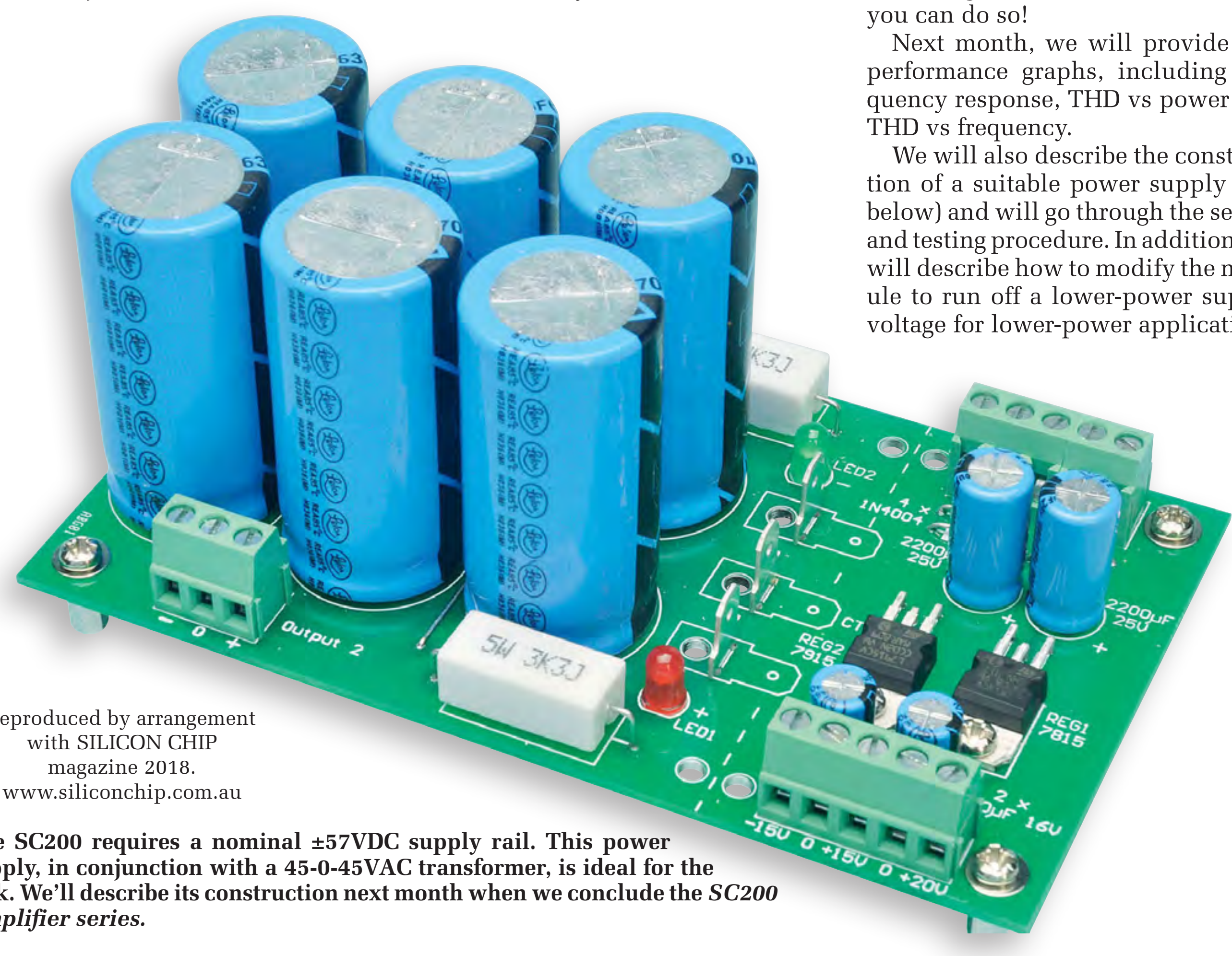
Note that a complete amplifier also requires a speaker protection module. This is important since a fault in the amplifier PCB can easily destroy your speaker(s) and even set them on fire! A suitable design in kit form is available from Altronics (cat K5167). This module will protect one or two speakers, so a stereo amplifier only requires one to be built.

Next month

Well, that's a lot to devour in one month – but at least we've given you all the construction details, so if you want to get stuck into construction, you can do so!

Next month, we will provide full performance graphs, including frequency response, THD vs power and THD vs frequency.

We will also describe the construction of a suitable power supply (see below) and will go through the set-up and testing procedure. In addition, we will describe how to modify the module to run off a lower-power supply voltage for lower-power application.



The SC200 requires a nominal ±57VDC supply rail. This power supply, in conjunction with a 45-0-45VAC transformer, is ideal for the task. We'll describe its construction next month when we conclude the *SC200 Amplifier series.*

High Power DC Motor Speed Controller - Part 2

Design by JOHN CLARKE

Continuing on from last month, here are the construction and setup details. We split the circuit into two sections/PCBs because it is such a high power design.

One PCB accommodates the control section, mainly involving the PIC16F88 microcontroller IC1 and the high-side driver, IC2.

The second is the switching or power side of the circuit, involving two or three (optional) MOSFETs and all the linking options to take care of high-side or low-side switching. In fact, this second board can be thought of as a single high-power MOSFET which can be wired for high or low-side switching.

Construction

Assembly simply involves building the two PCBs and connecting them together inside the compact diecast aluminium box which measures 119 × 94 × 57mm.

The control PCB is coded 11112161 and measures 107 × 82mm and it is installed on the bottom of the diecast case.

The power PCB is coded 11112162, and measures 111 × 85mm. It is installed on the lid of the diecast case and the two boards are connected together with five wires. Both of the PCBs are available from the *EPE PCB Service*. No heavy currents flow between the two PCBs so we don't need heavy-duty wiring for the interconnections.

Nor is there any heavy duty wiring between the power PCB and the various terminals for the DC supply and motor.

Instead, all the heavy duty currents flow in the tracks of the PCB which is manufactured using '2-ounce' copper, twice as thick as normally used. In addition, the four 50A-rated terminals are mounted directly on the PCB, with substantial tin-plated 'lands' to provide low resistance connections.

Furthermore, since six of the 'links' on the power PCB also carry heavy currents, they each have four paralleled tinned copper wire links, ie, LK1, LK2 and LK3 for high-side switching or LK4, LK5 and LK6 for low-side switching.

The component overlays for the two PCBs are shown in Fig.4 – power board at top and the control board below.

Start by assembling the control board and install IC2 first, as it is the only surface-mount component used in this project. Align the IC onto the pads and solder one corner lead to the PCB. Check that the IC is aligned correctly before soldering the remaining pins. You can re-align the IC easily by melting the solder joint and readjusting the position. Check that none of the IC leads are shorted with solder. Any excess solder can be removed with solder wick.

Next, you can install the resistors. We recommend that you use a digital multimeter to check the values of each resistor, as you install them. Note that the values for R1 and R2 are dependent upon the battery supply, as shown in Table 1, which is slightly modified from that in last month's issue.

Diodes D2 and D3, and ZD2 and ZD3 can be installed next. These need to be inserted with the correct polarity, with the striped end (cathode, k) oriented as shown in the overlay diagram.

Zener diode ZD4 is only used when the battery voltage is higher than 12V; Table 1 shows the required zener for 24V, 36V or 48V batteries. Note that for a 12V battery, when ZD4 is not required, JP1 is installed instead. Only if you are using low-side switching, install JP2 at the same time, otherwise it must be omitted.

There are five test points, at TP1, TP2, TP GND, TPS and TPV. To make them easy to use, we suggest that you install a PC stake at each point. Next, install the 18-pin DIL socket for IC1. Ensure it is oriented correctly.

Then you can install the capacitors, noting that the electrolytic types must be installed with the polarity shown on the overlay diagram. Note that the 10µF capacitor located just to the left of REG1 has a 63V rating, as shown on the diagram.

REG1 and REG2 mount horizontally on the PCB with their leads bent at 90° to allow them to be inserted into the holes. The metal tab is secured to the PCB using an M3 x 6mm screw and M3 nut. Secure each tab before soldering the leads.

Trimpots VR1 to VR7 come next. VR1 to VR6 are 10kΩ and may be marked as 103. VR7 is 50kΩ and may be marked as 503. Switch S2 is installed directly onto the PCB.

Terminal strips and LEDs

Terminal strips CON7 and CON8 are made by first dove-tailing two sections together. CON7 comprises a 3-way terminal with a 2-way section secured on each side. Similarly, CON8 is made by dovetailing a 3-way and 2-way terminal.

Orient these with the wire entry side adjacent to the edge of the PCB.

LED1-LED4 need to have their leads bent so they can protrude through the side of the diecast box. Each LED is mounted so the inside of the top lead is 15mm above the PCB.

Drilling the case

Now insert the control PCB inside the case. Mark the mounting hole positions and drill the required four 3mm holes.

Final PCB preparation involves attaching an M3 tapped × 9mm standoff to each corner mounting position.

The other holes in the side and lid of the case are shown in the diagram of Fig.5 on page 67. The required holes for the LEDs are 5mm in diameter and 25mm up from the outside base of the case. Do not forget to drill the hole at the CON7 end of the box for the cable gland. Drill this hole 25mm down from the top edge.

Mount the PCB onto the spacers with the M3 × 6mm screws. If using countersunk screws on the base, countersink the holes first. Secure to the base of the box with the M3 screws.

Power PCB assemby

Assembly of the PCBs can begin by installing the 4.7Ω gate resistors for MOSFETs Q1 and Q2, and 15V zener diode ZD1.

As already noted, the high-current links for low or high-side switching each consist of four sections of tinned copper wire. And we now repeat: only install LK1, LK2, LK3 and LK7 for high-side switching (HSS) or LK4, LK5, LK6 and LK8 for low-side switching (LSS). These links are shown in red for HSS and blue for LSS. **Do not install both sets otherwise you will provide a complete short circuit which will vaporise the fuse!**

Note that each set of HSS ***or*** LSS links must be soldered on both the top and bottom of the PCB.

Q1 and Q2 are mounted directly on the PCB and secured with M3 screws and nuts. Bend the leads to insert into the MOSFET holes on the PCB and solder the leads to the top and bottom of the PCB.

Diode D1 is mounted in the same manner. Note that it was installed differently on our prototype, but this has now been fixed.

Fuse and fuse clips

Now some notes about the fuse clips and fuse. The fuse holder clips are rated for a continuous current of up to 30A, although it is possible to fit a 40A fuse.

If the motor you intend to use with this controller is rated for a continuous current up to 30A, then there is no problem. Solder the fuse clips on both sides of the PCB.

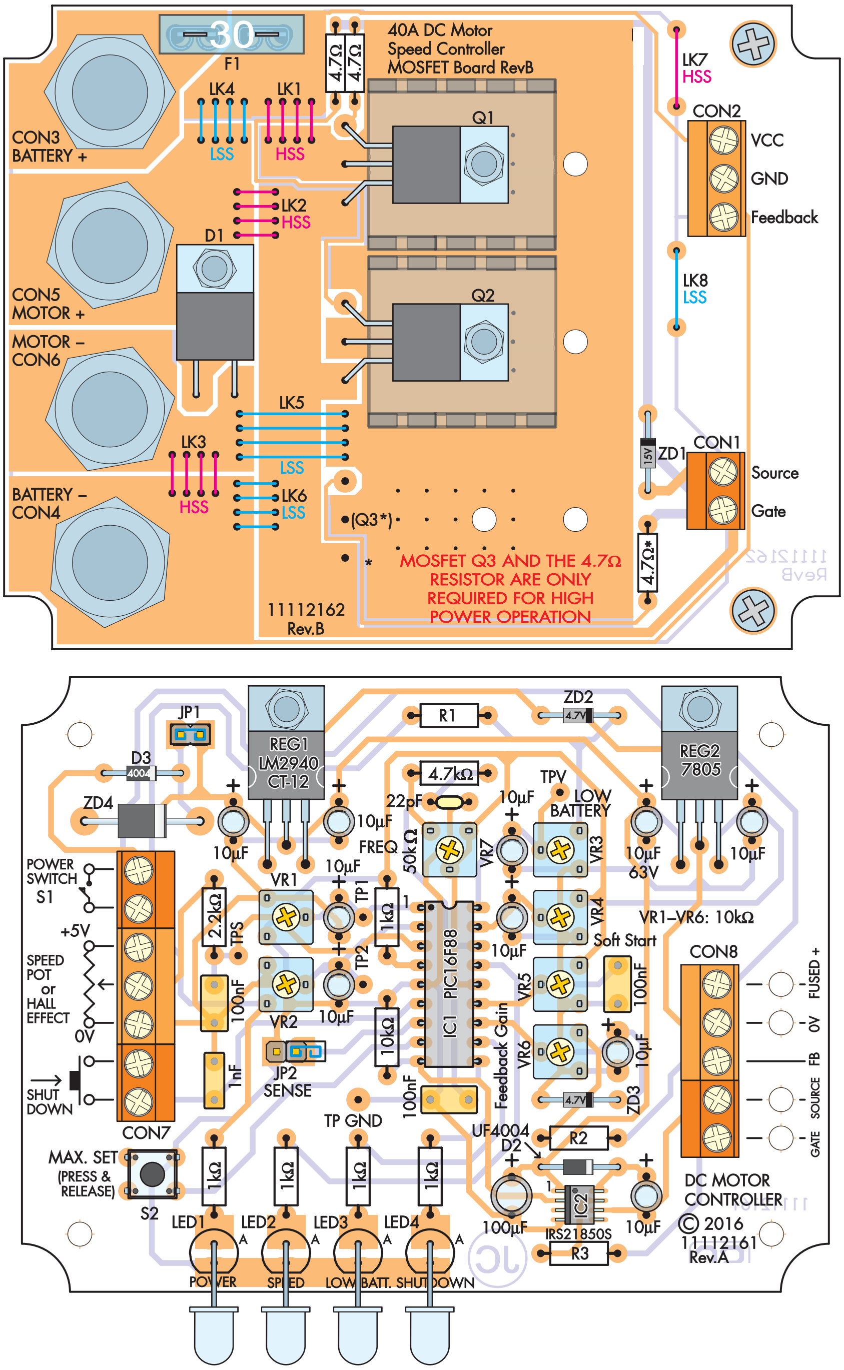


Fig.4: component overlays for the two PCBs – the power board at top and the control board at bottom. Again, we must reiterate that only one set of links (LK1-LK6) for either high-side switching (pink) or low-side switching (blue) can be fitted, otherwise the life-span of the fuse can be measured in milliseconds!

On the other hand, if your motor has a continuous current of up to 40A or more, the PCB-mount fuse clips will not be adequate.

In this case, the correct approach is to fit an in-line 5AG fuseholder in place of the 30A blade fuseholder (eg, Jaycar SZ-2065) together with a 40A 5AG fuse. The holes in the PCB which housed the 30A fuseholder may need to be enlarged slightly to fit heavy-current wires for the 5AG fuseholder.

Terminals CON1 and CON2 are mounted with the wire entry toward the outside of the PCB.

Install the two 12mm spacers on the underside of the PCB using two M3 screws.

The banana connectors/binding posts are unscrewed and the insulating bush arrangement fitted on top and the underside of the lid, then the nut is attached. The second nut goes on after the PCB is attached to the terminals. Use red for the Motor+ and Battery+ and black for the Motor– and Battery– terminals. Fig.6 shows the wiring connections between the two PCBs.

Make sure there is sufficient length for each wire so the terminal side of the 'power' PCB can sit over the CON8 terminals. The wires are secured with cable ties.

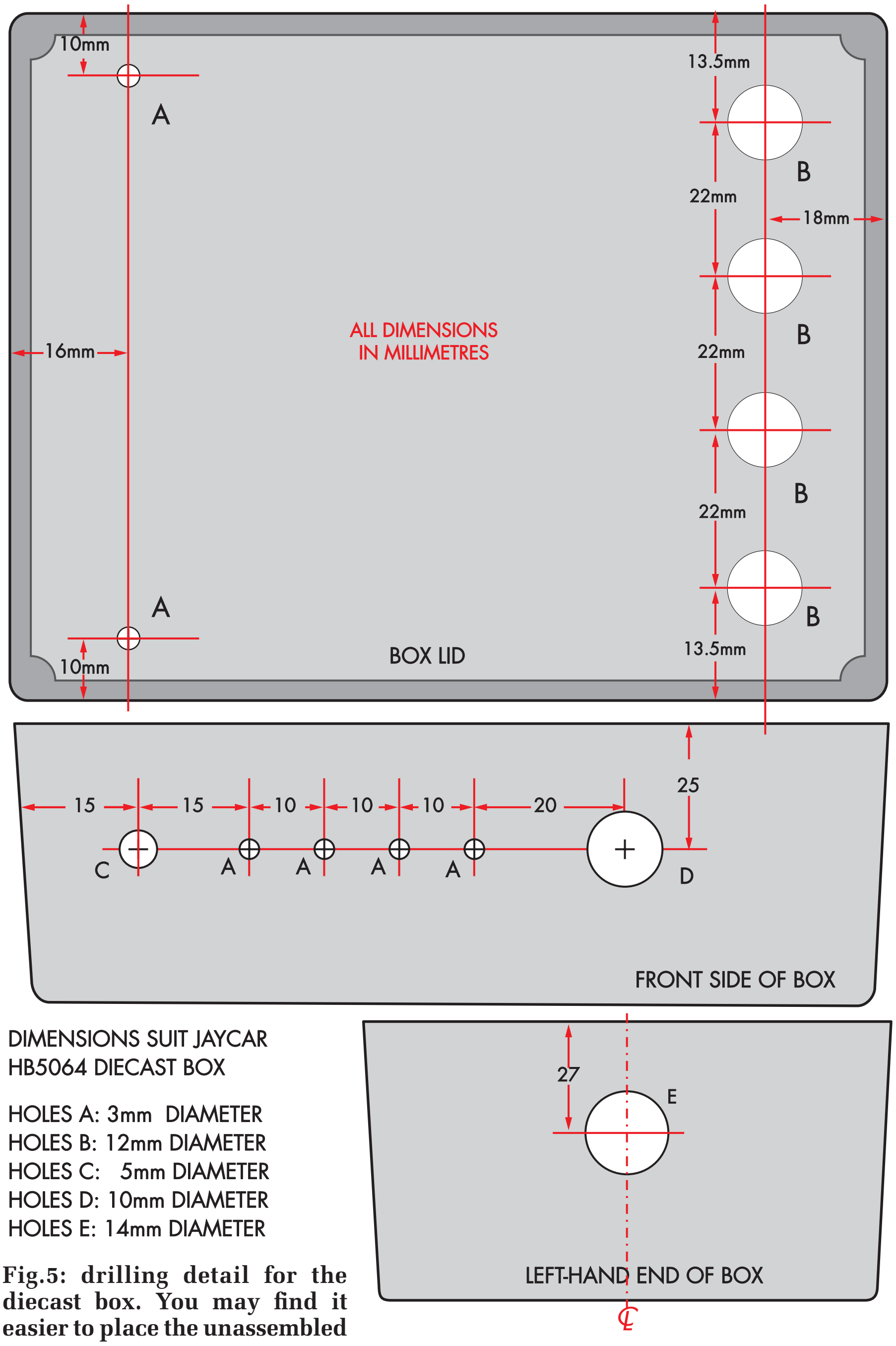


Fig.5: drilling detail for the diecast box. You may find it easier to place the unassembled 'power' PCB on the lid (underside) and use it as a template to mark out the lid holes – they're the only ones that are really critical.

For the main control PCB, there are holes available on the PCB in front of the screw terminals that allow cable ties to secure the wiring to the PCB for strain relief.

For our prototype, we installed the power switch on the side of the box adjacent to the Power LED and wired it to CON7. Similarly, the throttle can be installed in the box.

However, the switch and throttle would generally be used separate to the box, with the wires passing through the cable gland from CON8 and to a potentiometer or throttle. The emergency shut-down switch wiring would also pass through this gland.

Wiring to a motor

Unless the motor is to run at a full 30A load current continuously, 25A-rated wire could be used to make the battery and motor connections. Typically, this wire comprises 41 strands of 0.3mm tinned copper wire. These wires will fit through the binding post wire hole.

For higher current, use 56A wire (7 × 95 × 0.12mm wire). This wire won't fit through the post wire hole. However, you can crimp the wires first to 8mm ID crimp eyelets and secure these to the terminals.

Testing

With IC1 out of its socket, apply power between the Battery+ and Battery– terminals. Check that there is approximately 12V at the output of REG1 and 5V at the REG2 output. Rotate VR2 and VR3 fully clockwise and VR1, VR4, VR5 and VR6 fully anti-clockwise. Set VR5 mid way.

Nominal supply voltage	R1	R2	JP1 Inserted?	ZD4
12V	22kΩ	10kΩ	Yes	None
24V	56kΩ	27kΩ	No	10V 1W
36V	82kΩ	47kΩ	No	20V 1W
48V	91kΩ	68kΩ	No	30V 3W

Table 1: resistor, zener and jumper settings for various battery voltages.

If you are using a Hall effect throttle, monitor the voltage at TP1 as the throttle is rotated from minimum to maximum. Take note of the minimum and maximum voltage. Then set VR1 to the minimum voltage and VR2 to the maximum voltage.

Check that these settings are within the allowable range. See the specifications published in *Part 1* last month for the reference voltage settings. Now turn the power off and insert IC1.

Shut down

You can use the shut-down feature in one of two modes. Mode 1 is where normal motor speed control operation is restored once the throttle is returned to zero.

The second mode is where motor speed control operation is only restored when power is switched off and on again. Emergency shut down is indicated by LED4.

At every power up, this LED also lights up momentarily to indicate which mode is set. For the first mode, the LED blinks once and it blinks twice for the second mode.

To change the mode, press and hold the limit switch (S2) at power up. (Note that it is not the shut-down switch that is pressed at power up).

The mode will then change from one to the other. The shut-down LED will also flash once if it is the first mode that's selected, or twice for the second mode. The selected mode is stored in IC1 to be used subsequently.

Throttle limit

Press S2 and adjust the throttle for the maximum speed required from the motor. Release the switch at this speed.

In use, bringing the throttle beyond the speed limit will be indicated by the shut-down/limit LED lighting.

Low-battery threshold

The low-battery threshold is set by adjusting VR3 and measuring the voltage at test point TPV.

To make the adjustment, first decide on the low-battery cutout voltage required; typically 11.5V for a 12V lead-acid battery. Then measure the voltage at the switch S1 terminals or at the CON7 switch terminals when

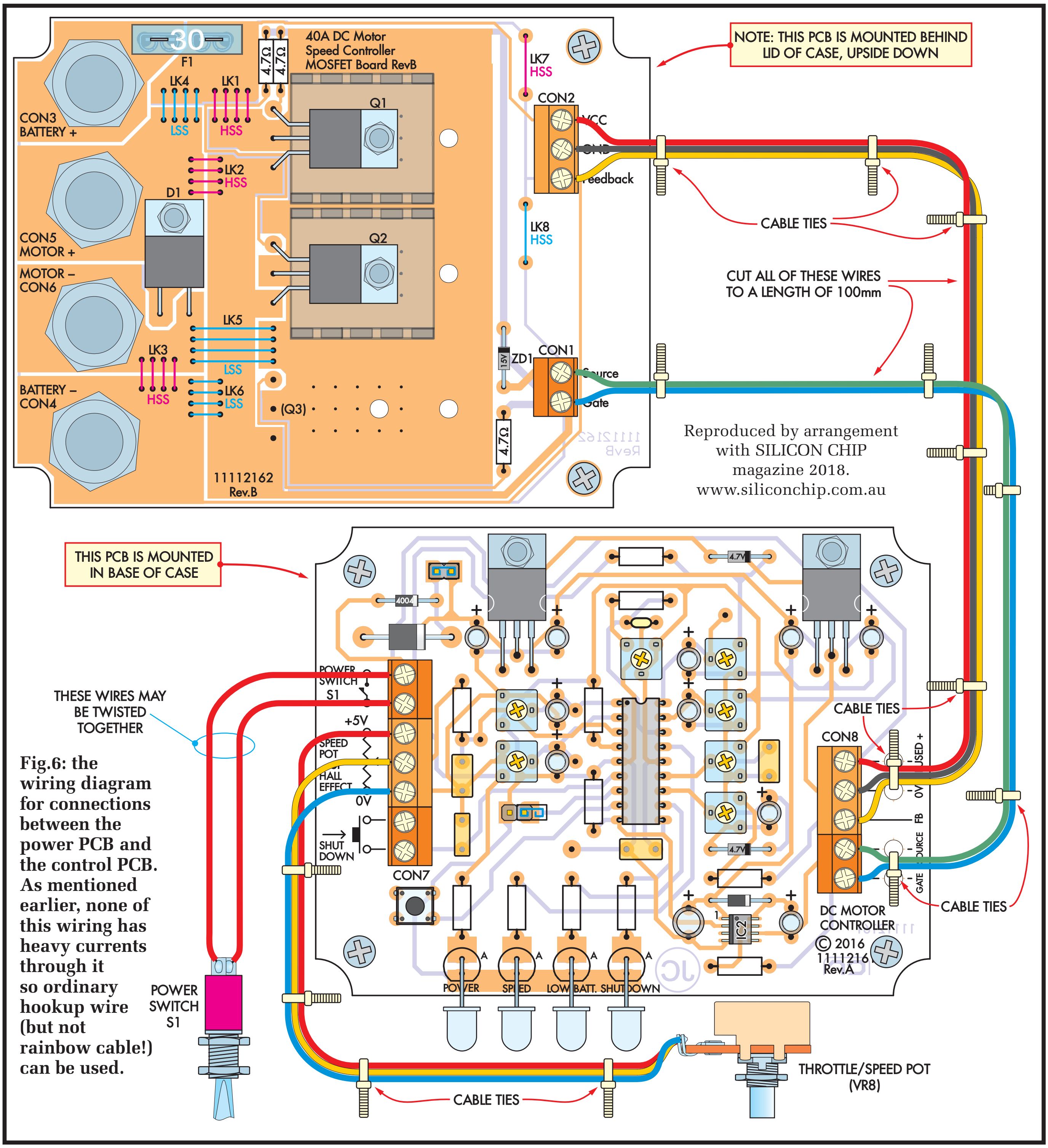


Fig.6: the wiring diagram for connections between the power PCB and the control PCB. As mentioned earlier, none of this wiring has heavy currents through it so ordinary hookup wire (but not rainbow cable!) can be used.

the switch is on and note it. Finally, measure the actual 5V supply (at the out terminal of REG2 – while the regulator has a nominal 5V output, it could be anywhere from 4.95V to 5.05V out).

Divide the voltage measured at S1 by the required low-voltage threshold value. Then multiply the result by one half of the actual 5V supply.

The formula is TPV = (voltage at S1 ÷ low-battery voltage value) x (the actual 5V supply ÷ 2).

Say, for example, the measured voltage at S1 is 13V and the required low battery shut-down voltage is 11.5V. Now divide 13V by 11.5V. The result of the calculation is 1.13. If the actual 5V supply is 4.95V, then half its value is 2.475V. Multiplying this by 1.13 gives a result of 2.80V.

Note that if you decide to change the low-battery threshold, the voltage at S1 needs to be re-measured and the TPV voltage recalculated and reset.

Adjusting feedback

Rotate the gain trimpot fully anticlockwise if you don't want motor speed feedback.

Otherwise, set the feedback control VR6 fully clockwise for high-side operaton (and fully anti-clockwise for low-side operation) and the gain control VR5 about one-third back from its fully anticlockwise position.

Then, with the motor running, rotate the feedback control anticlockwise (clockwise for low-side operation) until the motor just starts to increase in speed. Rotate slightly clockwise (anticlockwise for low-side operation), until the motor speed slows again. The gain control is then adjusted for the required amount of speed regulation when the motor is under load.

You can adjust the soft-start control VR4 and the frequency control VR7 to suit your particular motor and application.

Teach-In 2018

Get testing! – electronic test equipment and measurement techniques

Part 5: Inductors, resonant circuits and quartz crystals

by Mike Tooley

Welcome to *Teach-In 2018: Get testing! – electronic test equipment and measurement techniques*. This *Teach-In* series will provide you with a broad-based introduction to choosing and using a wide range of test gear, how to get the best out of each item and the pitfalls to avoid. We'll provide hints and tips on using, and – just as importantly – interpreting the results that you get. We will be dealing with familiar test gear as well as equipment designed for more specialised applications.

Our previous *Teach-In* series have dealt with specific aspects of electronics, such as PICs (*Teach-In 5*), Analogue Circuit Design (*Teach-In 6*) or popular low-cost microcontrollers (*Teach-In 7* and *8*). The current series is rather different because it has been designed to have the broadest possible appeal and is applicable to all branches of electronics. It crosses the boundaries of analogue and digital electronics with applications that span the full range of electronics – from a single-stage transistor amplifier to the most sophisticated microcontroller system. There really is something for everyone in this series!

Each part includes a simple but useful practical *Test gear project* that will build into a handy gadget that will either extend the features, ranges and usability of an existing item of test equipment or that will serve as a stand-alone instrument. We've kept the cost of these projects as low as possible and most of them can be built for less than £10 (including components, enclosure and circuit board).

This month

In this fifth part, *In theory* introduces inductors and the parameters that need to be measured when dealing with them. *Gearing up* introduces measuring instruments and techniques used for testing inductors, resonant circuits (where resistance, capacitance and inductance are all present at the same time), and quartz crystals. *Get it right!* helps you to avoid some of the pitfalls, providing some useful tips that will help you to improve the accuracy and relevance of your measurements. Finally, our fifth *Test gear project* is a quartz crystal checker that can also act as a handy calibration marker.

In theory: Measuring inductance and impedance

An inductor is an energy-storing device made up of a coil of wire (often comprising many turns) wound over a laminated steel, ferrite or air core. When current flows in the coil, a magnetic field is created in the core and in the space that immediately surrounds it. Inductors are specified in number of ways, including the value of inductance, tolerance and working current; they tend to fall within one of the following main types:.

- Inductors with laminated-steel cores
- Ferrite-cored inductors (often toroidal in shape)
- Air-cored inductors (with or without non-magnetic coil formers).

Depending on several factors (including the required value of inductance and operating frequency), different types of inductor are chosen for use in different applications. The type of inductor also has an impact on the tests and measurements carried out to determine whether it is functional and fit for purpose. For example, a large laminated-steel-core inductor will often have appreciable resistance due to the length of wire used in its construction. This results in a measurement that must take into account resistance as well as inductance, constituting an *impedance* rather than a pure inductance. We've summarised the properties of the main types of inductor in Table 5.1.

Equivalent circuit of an inductor

The equivalent circuit of an inductor is shows in Fig. 5.2. The components shown are:

- Effective inductance, L
- Parallel (or 'shunt') capacitance, C_P
- Equivalent series resistance (ESR), R_S
- Effective shunt resistance, R_P.

It is important to be aware that the additional components shown in Fig. 5.2 can affect the performance of an inductor. For example, at low frequencies, C_P is insignificant, but does become increasingly important at high and very high frequencies. R_P, on the other hand is of little consequence in low-impedance equipment (such as power supplies). Conversely, while R_S is unimportant in high-impedance circuits it becomes

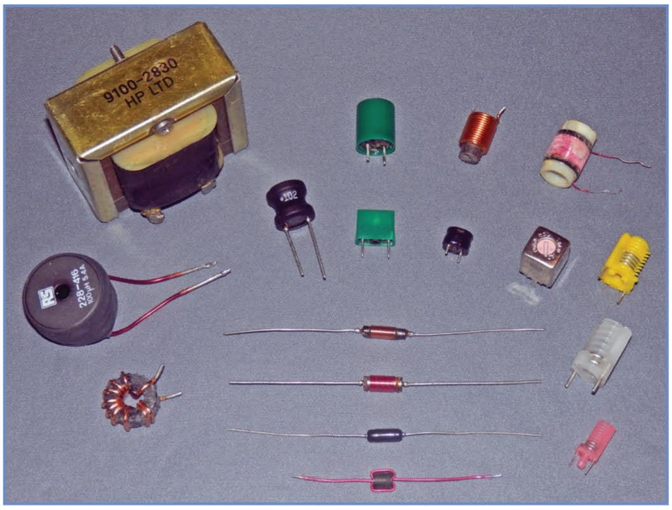


Fig.5.1 Different types of inductor with values ranging from 10µH to 10H

Table 5.1 Properties of various types of inductor

Type of inductor	Typical range of inductance	Typical tolerance	Typical resistance	Typical current rating	Typical applications
Laminated steel core	10mH to 10H	±10%	2Ω to 200Ω	500mA to 10A	Power and low-frequency applications
Ferrite core	10μH to 10mH	±5%	0.2Ω to 20Ω	1mA to 1A	Power supplies and filters
Air core	10nH to 10μH	±2%	0.01Ω to 1Ω	0.1mA to 100mA	RF tuned circuits and filters

critical in low-impedance situations (such as power supplies, amplifiers and switching circuits).

Effective series resistance (R_S)

The inductor's effective series resistance (R_S) is the internal resistance of the inductor expressed as a single resistance value considered to be connected in series with a perfect inductor. R_S is mainly attributable to the resistance of the (copper) wire used in an inductor's windings, but also takes into account the resistance of the connecting leads, contacts and tags (where appropriate). ESR is inversely proportional to frequency. In other words, as frequency increases, the 'copper loss' decreases.

While only a very small amount of power is dissipated in R_P, a very significant power can be dissipated in R_S when an appreciable current (either AC or DC) is flowing through the component. The power loss in R_S results in internal heating which can, in some cases, be responsible for impairing the properties of the magnetic core (this is particularly important with ferrite components used as filters and transformers in high-current power supplies).

Dissipation factor (D or DF)

The dissipation factor of an inductor is the ratio of the inductor's ESR to its reactance (X_L) at a specified frequency. As with a capacitor, dissipation factor is also referred to as 'tan δ' – ie, the tangent of the 'loss angle' of the inductor in which ESR (R_S) and reactance (X_L) are the adjacent perpendicular sides.

Since reactance (X_L) varies with frequency, an inductor's dissipation factor will also vary with frequency. Dissipation factor is usually quoted for sinusoidal AC power applications and is less meaningful when conditions are non-sinusoidal (as in switched-mode power supplies and class-C and D power amplifiers). Dissipation factor is given by:

$$D = \tan\delta = \frac{R_S}{X_L} = \frac{R_S}{2\pi fL}$$

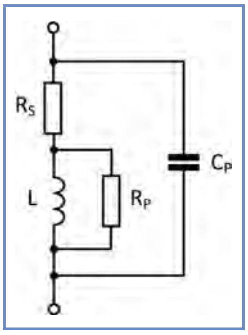


Fig.5.2 Equivalent circuit of a real inductor

To help put this into context, consider the following example. An inductor of 10H with an effective series resistance of 150Ω is used at a frequency of 50Hz. The dissipation factor is given by:

$$D = \frac{R_S}{2\pi fL} = \frac{150}{6.28 \times 50 \times 10}$$

$$= \frac{150}{6.28 \times 50 \times 10} = 0.048 \quad \text{(or 4.8\%)}$$

Quality factor (Q or Q_F)

Q is the ratio of inductive reactance (X_L) to effective series resistance at a specified frequency. Quality factor is the inverse of the dissipation factor. Hence:

$$Q = \frac{1}{D} \text{ and } D = \frac{1}{Q}$$

Thus, in the previous example, at 50Hz the inductor will have a Q-factor calculated from:

$$Q = \frac{1}{D} = \frac{1}{0.034} = 29.4$$

As with capacitors, most universal bridges (see last month's *Teach-In*) will allow you to measure Q and D to reasonable accuracy.

Shunt capacitance (C_P)

Shunt (parallel) capacitance is the effective capacitance of the inductor, including its connecting leads, tags or pins. It is important to be aware that this capacitance is made up of the sum of the component's internal capacitance (ie, the capacitance between winding turns) and the stray capacitance of its external connections.

Effective shunt capacitance reduces the effectiveness of an inductor at high frequencies. It is also responsible for a sharp rise in impedance that occurs at the component's *self-resonant frequency* (SRF). Depending on the inductor type, construction and value, the SRF occurs at frequencies of between about 1.3MHz for a 1mH ferrite cored choke to around 150MHz for a 1μH PCB-mounting component. Typical values of shunt capacitance range from between 10pF and 20pF for a 1mH ferrite choke, to less than 2pF for a 1μH PCB-mounted component. A large steel-cored inductor will have significantly higher values of C_P, but this is usually of little importance in low-frequency and power applications.

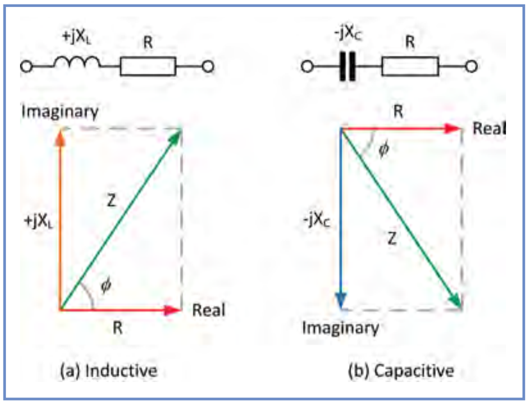


Fig.5.3 Impedance triangles for (a) inductive and (b) capacitive reactance

Measuring impedance

Impedance is an important parameter in a wide variety of electronic circuits and can be defined as the total opposition offered by a component or circuit to the flow of alternating current (AC) at a stated frequency. Unlike pure resistance in a DC circuit, impedance is a vector quantity that consists of a real part (resistance) and an imaginary part (reactance). The reactance can either be capacitive, $-jX_C$, or inductive, $+jX_L$. Note that the j-operator is used to indicate the quadrature phase angle with current leading or lagging voltage by 90° according to the sign placed immediately before the j-operator. Fig.5.3 illustrate this important relationship between resistance (R) reactance (X_C) and inductance (X_L). Note that the phase angle (ø) is defined as the angle between applied current (I) and voltage (V).

Resonant circuits

A resonant circuit is one in which there is resistance and a combination of both inductive and capacitive reactance present. In such circuits there will be one particular frequency at which the current and voltage are exactly in-phase and since the reactive components effectively cancel one another out the circuit behaves like one that contains only pure resistance. This can be extremely useful in a number of applications that require circuits to be selective, eg, accepting or rejecting current at a particular frequency.

Circuits that contain only a combination of resistance and pure capacitance or only a combination of resistance and pure inductance are 'non-resonant' because the voltage and current will not be in-phase at any frequency. More complex circuits, containing both types of reactance together with resistance are described as 'resonant' since

there will be one frequency at which the two reactive components will be equal but opposite. At this particular frequency, (known as the *resonant* or *tuned frequency*) the effective reactance in the circuit will be zero and the voltage and current will be in-phase.

The reactive components in a series LCR circuit will effectively cancel each other out when a circuit is resonant. We can thus determine the frequency of resonance (f_0) by simply equating the two reactive components, as follows:

$X_L = X_C$, and thus:

$$\frac{1}{2\pi f_0 C} = 2\pi f_0 L$$

Making f_0 the subject of this equation gives:

$$f_0 = \sqrt{\frac{1}{4\pi^2 LC}} = \frac{1}{2\pi\sqrt{LC}}$$

At resonance, the impedance of this circuit will simply be equal to the resistance, *R*.

In the case of a parallel resonant circuit (*L* connected in parallel with *C*) and where the inductor has resistance *R*, the frequency of resonance will be:

$$f_0 = \frac{1}{2\pi}\sqrt{\left(\frac{1}{LC} - \frac{R^2}{L^2}\right)}$$

At resonance the impedance of the circuit will be given by:

$$Z_d = X_C \times \frac{X_L}{R} = \frac{2\pi fL}{2\pi fC} \times \frac{1}{R} = \frac{L}{CR}$$

This is often referred to as the *dynamic impedance* of the resonant circuit.

Q-factor

The *Q*-factor (or *quality factor*) is a measure of the 'goodness' of a tuned circuit and is sometimes also referred to as its *magnification factor*. In the case of a series tuned circuit, the *Q*-factor simply tells you how many times greater the inductor or capacitor voltage will be than the supply voltage. The better the circuit the higher the voltage magnification and the greater the *Q*-factor. Conversely, for a parallel circuit, the *Q*-factor tells you how many times greater the inductor or capacitor current will be than the supplied current. When dealing with resonant circuits it is thus important to have a means of measuring *Q*-factor as well as impedance. Practical values of *Q* for a resonant circuit range from about 20 to 200.

Gearing up: Testing inductors and resonant circuits

Measuring inductance

The value of inductance (*L*) can be measured in various ways. The traditional method is that of using an AC bridge arrangement, like that shown in Fig.4.3 last month. The bridge is adjusted for a null on the indicator and in this condition is said to be 'balanced'. In the balanced condition the value of inductance is read and interpolated from a calibrated scale. Note that some bridges incorporate provision for injecting a DC bias or for making use of external AC excitation. Automatic bridges are also available, and these eliminate the need for the manual balancing operation.

LCR meters

Unfortunately, while modern multimeters often incorporate capacitance ranges they very rarely incorporate inductance measuring facilities. Fig.5.4 shows an exception to this rule in the form of

Fig.5.4 A low-cost multi-range LCR meter

Fig.5.5 The Peak Electronics LCR40 being used to check the value of a small steel-cored inductor

a low-cost portable multi-range LCR meter available for purchase on-line for around £10. This instrument doesn't have the usual current and voltage ranges but instead has no less than nine resistance ranges, six capacitance and four inductance ranges. For good measure, this particular instrument also measures transistor current gain!

Instruments like the Peak Electronics LCR40 and LCR45 (described last month) can be a useful investment if you need to measure inductors on a regular basis and with a reasonable degree of accuracy. Note that, in addition, the Peak Electronics LCR45 measures complex impedance, complex admittance (both displayed in rectangular form) as well as the magnitude and phase of impedance displayed in polar form. Fig.5.5 shows the Peak LCR40 being used to measure the inductance of a steel-cored choke. Additional information can be obtained by simply scrolling the display.

Measuring impedance

Impedance measurement tends to be a little more complicated than simple inductance and capacitance measurement. However, several different methods are available, including:

- Manual or automatic impedance bridges
- Measurements based on resonance
- V-I techniques
- Network analysers.

Table 5.2 shows a comparison of the

Instrument or method	Advantages	Disadvantages	Typical frequency range	Typical application
Manual or automatic AC bridge	Accuracies of better than 0.5% can be achieved	May need manual adjustment and balancing	DC to well over 50MHz	Laboratory testing
Resonance	Only suitable for high-*Q* components	Requires manual adjustment	100kHz to 10MHz	Tuned circuits and other high-*Q* measurements
V-I method	Can be easily performed using readily available test instruments	Requires calculation using separate voltage and current measurements	50Hz to 1MHz (RF V-I instruments are available but can be expensive)	Low-*Q* inductors used in AC power and audio frequency applications
Network analyser	Very wide frequency range coupled with high accuracy	Expensive, may need recalibration at different frequencies	1MHz to 1GHz	Laboratory analysis and circuit design

Table 5.2 Comparison of impedance measuring techniques

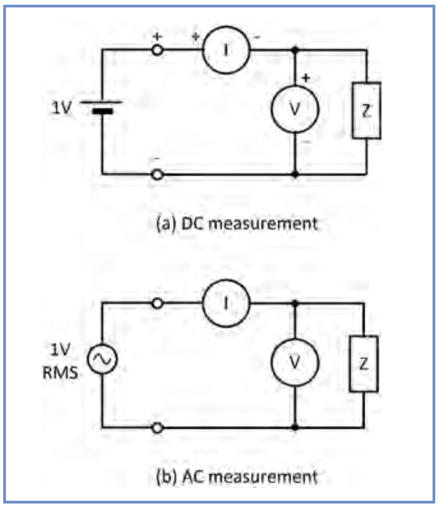


Fig.5.6 The V-I method of impedance measurement

above methods. Note that several of these methods require expensive test equipment.

Using the V-I method

The V-I method of inductance/impedance measurement can be quite effective and will yield useful results with reasonable accuracy. It is thus ideal for 'one-off' measurements. Fig.5.6 shows the simple arrangement used by the author. Two sets of measurements are required, one at DC and the other using an AC source. The unknown impedance is first connected to a DC power supply, as shown in Fig.5.6(a). The power supply (virtually any variable bench power supply will be suitable) is then adjusted until the DC voltmeter reads exactly 1V. At this point the DC current is measured and recorded.

Next, the unknown impedance is connected to an AC source, as shown in Fig.5.6(b). The AC source can be a signal generator with a low output impedance or a 50Hz transformer with a low voltage secondary winding and a suitably rated variable resistor connected in series with the secondary. The frequency of the AC source is set to the required test frequency (usually 50Hz, 100Hz or 400Hz) and the AC voltage is adjusted until the AC voltmeter reads exactly 1V.

At this point, the AC current is measured and recorded. Tests are often carried out at 50Hz or 100Hz for large inductors and at 400Hz, 1kHz or 10kHz for smaller ferrite-cored inductors. The recorded values can then be entered into a spreadsheet (available for download from the *EPE* website) and the impedance can then be automatically calculated (see Figs.5.7 and 5.8). The spreadsheet will save you having to perform several error-prone calculations by hand. The accuracy of this method is often comparable with other methods and will usually yield a result that is better than ±5%.

Q-measurement

Q-factor can be measured using various methods, but the most simple and convenient method is with the aid of a dedicated *Q*-meter. This instrument comprises a very low-impedance variable-frequency source together with a sensitive RF voltmeter. Typical examples of instruments that become available on the second-hand market from time to time are the Advance T2 (see Fig.5.9) and the Marconi TF1245 *Q*-meter. More complex network analysers have largely superseded such instruments, but they can still be invaluable if you design and/or manufacture resonant *LC* circuits on a regular basis. They also tend to be (much) more affordable than network analysers. Fig.5.10 shows typical results obtained from the author's *Q*-meter when designing a high-*Q* inductor for use in a high-power antenna tuner. To reduce losses, the 44µH inductor was manufactured using silver-plated copper wire wound on a large ceramic former and, as can be seen, it manages to achieve a *Q*-factor of 150 with a shunt capacitance of 40pF at a measurement frequency of 3.4MHz.

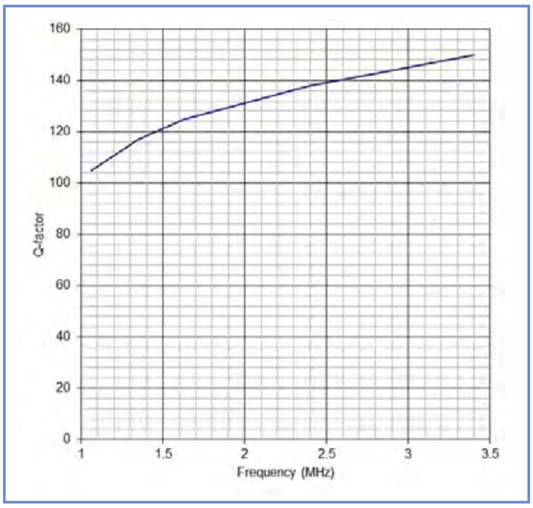


Fig.5.10 Variation of Q-factor with frequency for the inductor shown in Fig.5.11

Fig.5.9 An Advance Electronics T2 Q-meter

Dip meters

A hand-held dip meter (see Fig.5.12) provides a very simple method of measuring the resonant frequency of a tuned circuit. The instrument comprises a variable frequency RF oscillator and a meter that either responds to the amount of current supplied to the oscillating device (eg, the collector current of the oscillator stage) or is arranged to indicate the RF voltage appearing across the oscillator *LC* 'tank' circuit. In use, a coil is selected from those supplied with the instrument

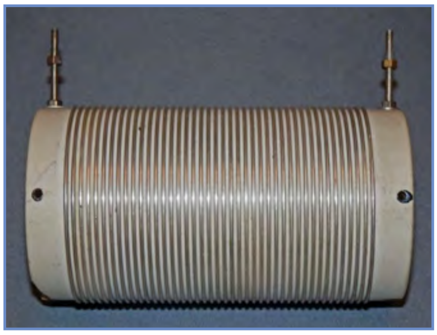


Fig.5.11 A large air-cored 44µH inductor wound on a low-loss ceramic former

V-I Method		
1. Apply 1V DC to the component or circuit.		
2. Select an appropriate DC current range.		
3. Measure the DC current flowing and enter it here:	230	mA
4. Apply 1V AC to the component or circuit		
5. Enter the AC signal frequency here:	100	Hz
6. Select an appropriate AC current range.		
7. Measure the AC current flowing and enter it here:	125	mA

Calculated results:		
	Impedance, Z =	8.00 ohm
	Resistance, R =	4.35 ohm
	Reactance, X =	6.72 ohm
	Inductance, L =	10.69 mH
	Power factor, PF =	0.543

Fig.5.7 Spreadsheet analysis of V-I results for a 10mH ferrite-cored inductor

V-I Method		
1. Apply 1V DC to the component or circuit.		
2. Select an appropriate DC current range.		
3. Measure the DC current flowing and enter it here:	900	mA
4. Apply 1V AC to the component or circuit		
5. Enter the AC signal frequency here:	100	Hz
6. Select an appropriate AC current range.		
7. Measure the AC current flowing and enter it here:	45	mA

Calculated results:		
	Impedance, Z =	22.22 ohm
	Resistance, R =	1.11 ohm
	Reactance, X =	22.19 ohm
	Inductance, L =	35.34 mH
	Power factor, PF =	0.050

Fig.5.8 Spreadsheet analysis of V-I results for the steel-cored inductor shown in Fig.5.4

Fig.5.12 A wide-range dip meter covering 1.5MHz to 250MHz in six ranges

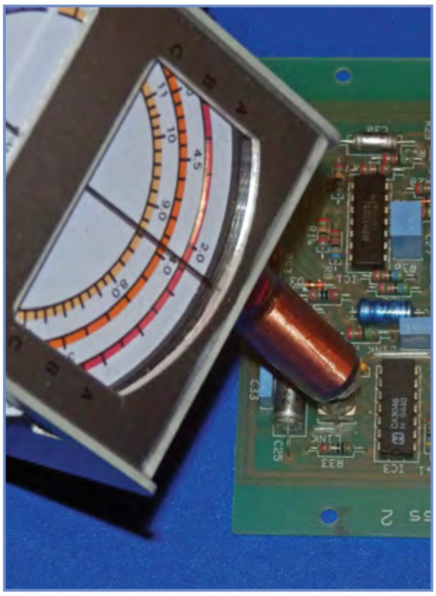


Fig.5.13 Using the dip meter to check a resonant circuit

Get it right when carrying out impedance, resonance and Q-measurement

- Always ensure that your measurements are made at an appropriate frequency. For example, when using the V-I impedance method ensure that the AC measurement is made at a frequency that's within the expected operating range for the component being tested
- When measuring small values of inductance, ensure that measurements are carried out with the shortest possible test leads. If using a hand-held instrument (like the Peak LCR40 and LCR45) ensure that the test probes are calibrated by opening and shorting them immediately before making a measurement. If using a bench instrument for testing inductors it is best to connect the component directly to the instrument (ie, without using test leads or prods)
- When using a *Q*-meter, ensure that the inductor is mounted well away from any ferromagnetic or ferrite components. It should also be supported clear of any grounded parts (such as the case of the instrument itself)
- When using a hand-held dip-meter ensure that there is adequate coupling between the instrument and the resonant circuit on test. Furthermore, some instruments will display false dips, so it can be useful to carry out an initial frequency sweep before attempting to make a measurement (the initial frequency sweep will reveal any problems before you attempt to locate a dip)
- When using an impedance bridge, select a higher range and work downwards, progressively increasing the sensitivity of the instrument in order to obtain a sharp null indication
- Self-resonant frequency (SRF) measurements can be misleading unless you are able to minimise the effects of stray capacitance and inductance resulting from instrument connections
- Don't rely on measurements where component values may be towards the end of the instrument's measuring range (accuracy will be impaired as the instrument's limits are approached).

covering the expected frequency range and then inserted into a socket on the hand-held unit. The sensitivity control is adjusted for a mid-range indication and the coil is held in close proximity to the *LC* circuit on test. This is accomplished with the coil held end-on to the inductor or resonant transformer to maximise inductive coupling, as shown in Fig.5.13. The oscillator frequency control is then carefully swept across the expected range while observing the meter indication. When the oscillator frequency matches that of the resonant circuit, energy is coupled into the circuit on test and, as a consequence, there is a sudden dip in the meter indication. The MFJ-201 dip meter shown in Fig.5.12 covers 1.5MHz to 250MHz in six ranges and this handy device can also operate as an absorption wavemeter and quartz crystal checker (see later).

Test Gear Project: Handy Crystal Checker

Quartz crystals are widely used in electronic circuits when an accurate reference frequency is required. A quartz crystal undergoes mechanical deformation when a voltage is applied across its faces. Conversely, a voltage is developed across the same faces when it is mechanically deformed. This phenomenon is known as the *piezoelectric effect* and it has several useful applications in electronics, including accurate frequency control of oscillators.

Quartz crystals used in electronic circuits usually consist of a thin slice of quartz. Opposite slice faces have electrodes made from a thin film of deposited gold or silver. Fine wires are soldered at nodal points on each electrode and the complete assembly is enclosed in an evacuated glass or metal envelope. Lead-out pins or wires are connected to external circuitry. The type of encapsulation, size, dimension and pin-spacing varies from one type of crystal to another. Some of the most common crystals are the HC18/U types that are miniature, metal encapsulated wire-ended types which may be soldered directly to a PCB without sockets. A similar type, fitted with pins for connection to a socket is the HC25/U (see Fig.5.14).

Fig.5.14 A selection of crystals with fundamental resonant frequencies of 32kHz to 18MHz

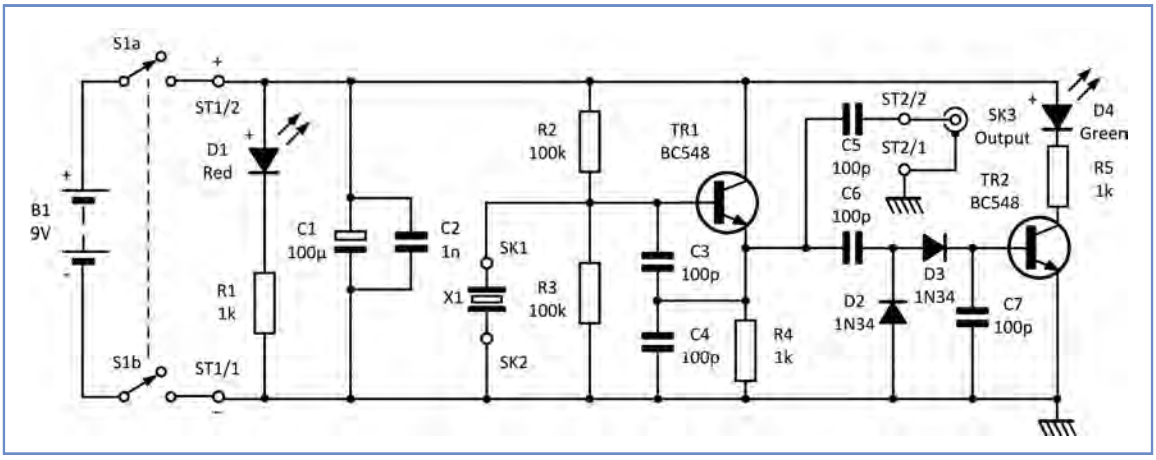


Fig.5.15 Complete circuit of the Handy Crystal Checker

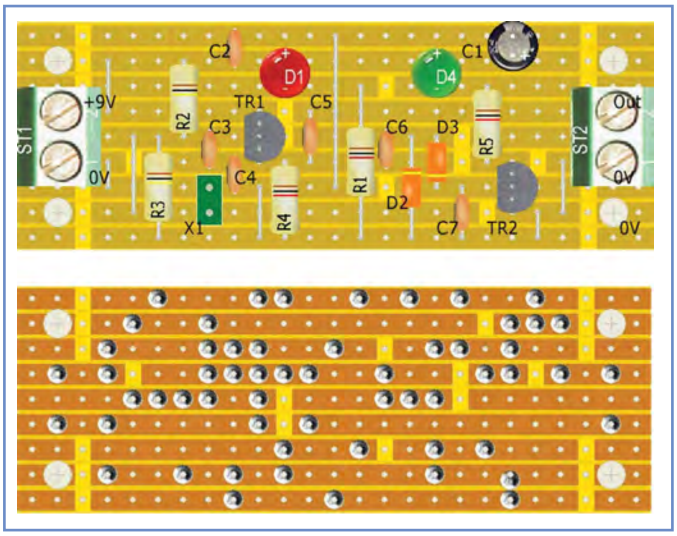


Fig.5.16 Stripboard layout of the Handy Crystal Checker

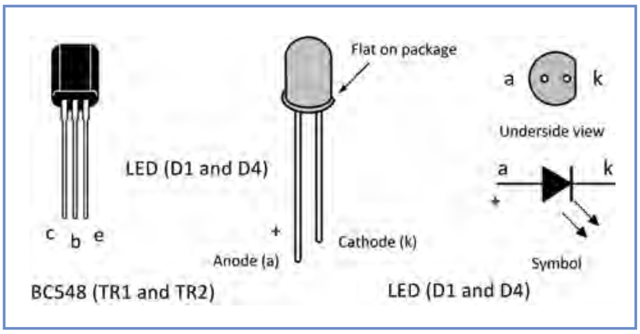


Fig.5.17 LED and transistor pin connections

Quartz crystals exhibit Q-factors that are many times larger than those that can be obtained with even the very best LC tuned circuits. The reason for this is that the ratio of equivalent inductance (L) to series loss resistance (R_S) is exceptionally high. It's also worth noting that the stability that can be attained by a crystal is directly related to its Q-factor. In other words, the higher the Q-factor the greater will be the stability of the output derived from a crystal-controlled oscillator.

Fundamental versus overtone operation

Crystals, and their associated oscillator circuits tend to fall into one of two main classes – fundamental and overtone. Crystals manufactured for fundamental operation are designed to oscillate at their basic resonant frequency, whereas those intended for overtone operation oscillate at, or very near, a whole number multiple of their fundamental resonant frequency. Generally, the third overtone is preferred, although fifth, seventh, and even ninth overtone devices are available. At high frequencies, crystals become extremely thin and are consequently more difficult and more expensive to manufacture. As a result, fundamental crystals are normally used at frequencies up to about 20MHz; beyond this, overtone units are usually employed. Note that, since the properties for a given crystal unit may be different at an overtone frequency when compared with its fundamental resonance, no reliance should be placed on the behaviour of a crystal at any frequency other than that for which it is designed.

Our handy crystal checker will allow you to test fundamental crystals between 2MHz and 20MHz and third/fifth overtone components from 20MHz up to 120MHz. Note that overtone crystals will be tested at their fundamental frequency so that, for example, a 48MHz third-overtone crystal will be operated at its fundamental resonant frequency of 16MHz.

The complete circuit of our *Test Gear Project* is shown in Fig.5.15. The circuit comprises a fundamental Colpitts oscillator stage (TR1) followed by a detector (D2 and D3) and a DC amplifier (TR2). Two LED indicators are fitted; D1 (red) indicates that the circuit is switched on while D4 (green) indicates oscillation and that the quartz crystal is functional. In addition, the output waveform is made available at a BNC connector (SK3). This makes it possible to connect an oscilloscope, digital frequency meter or small antenna.

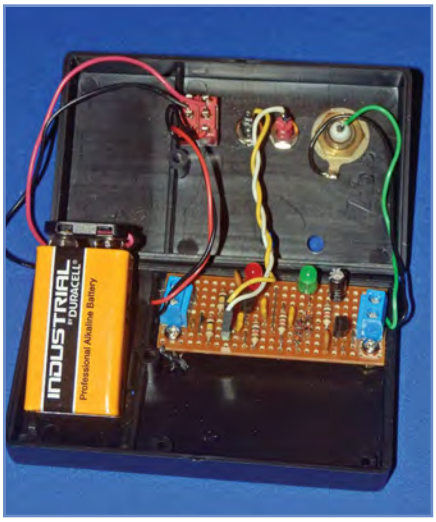


Fig.5.18 Internal wiring of the Handy Crystal Checker

Fig.5.19 External appearance of the finished Handy Crystal Checker

You will need

Perforated copper stripboard (9 strips, each with 25 holes)
2 2-way miniature terminal blocks (ST1 and ST2)
1 ABS case with integral battery compartment
1 9V PP3 battery clip
1 9V PP3 battery
1 Miniature DPDT toggle switch (S1)
1 Red 2mm panel-mounting socket (SK1)
1 Black 2mm panel-mounting socket (SK2)
1 Chassis-mounting BNC connector (SK3)
1 2-way PCB header (X1)
2 BC548 transistors (TR1 and TR2)
2 1N34 diodes (D2 and D3)
1 5mm red LED (D1)
1 5mm green LED (D4)
3 1kΩ resistors (R1, R4 and R5)
2 100kΩ resistors (R2 and R3)
1 100µF 16V radial electrolytic (C1)
1 1nF 63V ceramic capacitor (C2)
5 100pF 63V capacitors (C3 to C7)
1 Optional crystal holders (see text)

Assembly

Assembly is straightforward and should follow the component layout shown in Fig.5.16. Note that the stripe on D2 and D3 marks the cathode connection, while the '+' symbol shown on D1 and D4 indicates the more positive (anode) terminal of the two LEDs. The pin connections for the LEDs and transistors are shown in Fig.5.17. The reverse side of the board (*not* an X-ray view) is also shown in Fig.5.16. Note that there's a total of 21 track breaks to be made.

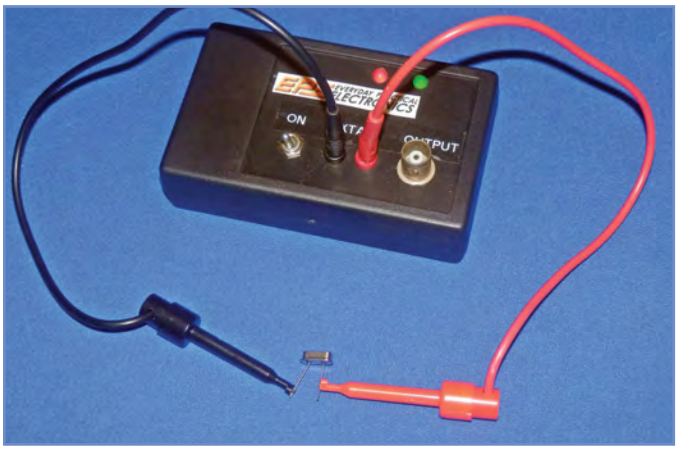


Fig.5.20 Using the Handy Crystal Checker to check a wire-ended crystal

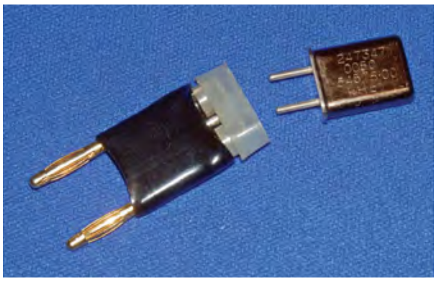


Fig.5.21 An adapter for testing HC25/U crystals

These can be made either with a purpose designed spot-face cutter or using a small drill bit of appropriate size. There are also seven links that can be made with tinned copper wire of a suitable diameter or gauge (eg, 0.6mm/24SWG). When soldering has been completed it is very important to carry out a careful visual check of the board as well as an examination of the track side of the board looking for solder splashes and unwanted links between tracks. The internal and rear panel wiring of the semiconductor junction tester is shown in Fig.5.18. Note that the PCB header connector (X1) is wired to ST2.

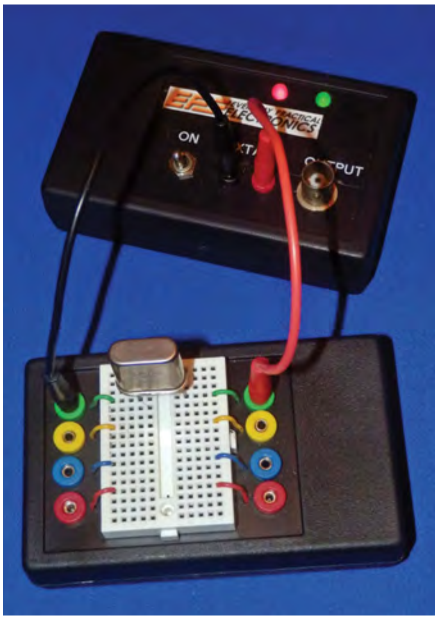


Fig.5.22 Using the breadboard text fixture to test a wire-ended HC6 crystal

Setting up

No setting up is required after assembly – all you need to do is to connect a PP3 battery and switch on! D1 should become illuminated – if not, check the battery and circuit connections carefully. Next, connect a quartz crystal (ideally, a fundamental mode unit in the range 4MHz to 14MHz) to SK1 and SK2, as shown in Fig.5.20. The green LED (D4) should then become illuminated to confirm oscillation. Figs.5.21 and 5.22 show how the *Handy Crystal Checker* can be used to test HC25/U and wire-ended HC6 crystals respectively. In the former, to simplify connection, we have constructed a simple adapter using two 2mm connectors and an HC25/U crystal socket covered with a short length of heat-shrink sleeving.

If required, you can easily check the frequency of oscillation by connecting a digital frequency meter or an oscilloscope to SK3, as shown in Fig.5.23. Alternatively, you can check the frequency of operation by connecting a short wire to the centre of the BNC connector and tuning a nearby radio receiver to locate the signal produced. In *Part 7* of our *Teach-In 2018* series we will show how a low-cost 'dongle' can be used with appropriate software to construct a basic software defined radio (SDR) which will provide you with a useful and inexpensive method of measuring a wide variety of RF (radio frequency) signals at frequencies from 150kHz to 1.5GHz.

Next month

Next month's *Teach-In 2018* will look at audio frequency tests and measurements. Our project will feature a low-distortion audio frequency test signal source.

Part 3 – ooops!

My thanks to Dr JCC Nelson from Horsforth, Leeds. He spotted an error in Fig.3.9 (*Teach-In 2018, Part 3*). The inputs to the 741 op amp (IC1) are incorrectly labelled and need to be swapped: '+' to '–' and vice versa. Fortunately, the stripboard layout is correct and the circuit will operate as designed and described.

Fig.5.23 Using a digital frequency meter to check the fundamental frequency of an HC25/U crystal

NET WORK

by Alan Winstanley

Echoing the answer

ASTONISHINGLY, some four years have already passed since this column first hailed the new generation of Internet-of-Things devices and appliances that were coming over the horizon. They would prove to be the forerunners of many 'smart' new things to arrive. In April 2014's column, for example, I mentioned the new WeMo smart sockets and devices from Belkin, and a year later came Amazon's Echo (August 2015, *Net Work*), a smart loudspeaker featuring a voluble new interactive helper called 'Alexa'.

Electronic voice synthesis has come a long way since the seminal 1970s Speak & Spell electronic spelling game designed by Texas Instruments (try the Speak & Spell Simulator at: **www.speaknspell.co.uk** – requires Flash – or Speak and Spell for Android, available in the Google Play Store). Just a year or two later, in 1982 I rushed home clutching a new Mattel Intellivoice speech synthesis add-on for my Intellivision TV game console. The console's first electronically generated speech-enhanced game was Space Spartans (sold separately), which, along with the Intellivoice, would cost £350 in today's money. As a young chap, I was spellbound by these computerised voices and colourful graphics – and I'd never seen or heard anything like it. As a salute to those early days of digitised elocution, my Windows PC boots up with 'Hello Commander, Computer Reporting', the original 1980s Space Spartans speech sample, which, joyfully, has been made available on Intellivisionlives.com. (You can use free Winaero Tweaker to set your Windows default startup sound if necessary – see **https://winaero.com**)

You can experience 1970s voice digitisation with the Texas Instruments Speak and Spell Simulator *(needs Flash) hosted at Speakandspell.co.uk*

Fast-forward more than a third of a century to those near-perfect voices entombed in Google Assistant, Amazon's Alexa and Microsoft's Cortana, and the era of voice-controlled artificial intelligence has well and truly arrived. There has been a growing choice of IoT smart devices and wider acceptance of network control – British Gas now claims more than half a million British homeowners use Hive smart thermostats to control their heating systems. It's become easier than ever to manage many everyday tasks around the house or get help when you need it by talking to a user-friendly smart speaker hosted on a domestic Wi-Fi network.

Black Friday bonanza

So-called Black Friday and Cyber Monday are two November sales events imported directly from the US – Amazon UK claims to be the 'home of Black Friday' – and these dates have entrenched themselves firmly in the savvy shopper's calendar. Many High Street shops in Britain were almost empty on Black Friday, as shoppers sought out the best deals online. I too buckled under the onslaught of countless emails and TV adverts, and an Amazon 30% Black Friday deal on their Amazon Echo Dot smart speaker proved irresistible. It was Amazon's bestseller on Black Friday.

One of these Wi-Fi-powered plastic pucks was soon perched on a table, displaying a colourful halo of lights. For a few pounds more, a TP-Link mains smart plug was included in an Amazon bundle. And, not forgetting the free Philips Hue smart bulb that the John Lewis store chain used to reward me for buying an insurance policy, it looked as though my home smart network was finally taking shape!

The Echo Dot is Amazon's smallest standalone smart loudspeaker, and this second-generation device builds on the Alexa experience following its launch in the UK last year. Installation of the Echo Dot started by downloading the Alexa app onto a smartphone, but the author's SoHo router defeated the gadget's auto setup process. After manually configuring the logins, a minute or two later the Echo Dot was humming away on the home network.

The Echo Dot is just 83mm in diameter by 32mm high, mains-powered and has a 3.5mm speaker jack – or it can stream audio via Bluetooth. Pushbuttons on top can disable the microphone, change volume or access setup. The Amazon Alexa app handles configuration settings, starting with some basics: metric or imperial units for weather and distance, as well as choosing a 'Flash Briefing' or streaming news content – BBC News is enabled by default – but hundreds of other news sources or 'skills' are available – including, for example, Gerry Anderson News (1960s TV series news, merchandise…) or newspapers and sports clubs. Owners of the new Echo Show with built-in LCD screen would enjoy enhanced video news feed as well.

Out of interest, a National Grid Usage 'Flash Briefing' states the current total UK electricity power consumption (40.98GW, Alexa informed me). Any number of sports and news feeds can be configured in the app, assuming you have the patience to listen to them! The Alexa app can link with Google, Outlook and iCloud calendars and will read out your schedule. The app can configure 'Routines' similar to a macro of tasks, which will also work with compatible smart devices such as Philips Hue LED bulbs.

Amazon's Echo Dot smart speaker was Black Friday's bestseller in 2017

Teaching new skills

A range of 'skills' adds new features, such as a wind chime player or 'Fun Facts'. This latter skill helpfully stated that 18 acres of pizza are eaten in America every day. Skills are easily added online via the Amazon website. Worth knowing about are separate IFTTT (If This, Then That) 'recipes' or services, enabling an Amazon Echo to perform some task-specific duties, but the range is very limited so far. See **https://ifttt.com/amazon_alexa** and check out applets for other devices and services too. (One IFTTT service pings me a notification when the International Space Station passes overhead, for example.)

Alexa's English accent is easy enough on the ear, and my first impression was that the gadget's responsiveness was nothing short of remarkable. Prefixing every utterance with the wakeword 'Alexa' can become tiresome (you can also choose Echo, Amazon or Computer), but usually the Echo Dot turns up trumps when dealing with everyday questions or simple tasks. Ask it the weather, set an alarm, crack a joke, read out the BBC News headlines (or UK power consumption) or play music hosted on your Amazon account, Alexa generally tackles these reliably and without fuss. It's worth remembering that each time you buy a music CD from Amazon, a free MP3 copy is hosted on your account so you can listen using Amazon apps or an Echo: some Amazon customers have rediscovered long-forgotten music CDs in their Amazon library this way. Alexa will start streaming your favourite music, and can be told to pause, next (skip) or stop playing after so many minutes, change the volume or act as a sleep timer, and it can sound an alarm after a period of time. Set an alarm for 9 o'clock and Alexa will ask, morning or evening?

The Amazon Echo Dot can also handle multi-room music, and it can call and message family or friends who have opted in with their own Echo devices and app. This could be a boon, especially for elderly or infirm users. Overall, the Echo Dot offers plenty of scope for first time users to sample what smart home networking can now offer at a modest cost.

Rival devices include the Google Home, the Google Home Mini pod (Google's answer to the Echo Dot) and Home Max speaker, featuring Google Assistant, which recognises up to six different voices for a more personalised experience. The ability to 'broadcast' messages around the area, Tannoy-style, is also taking off, as both Echo and Google Home are given more duties to perform.

Meanwhile, Apple's attempts to launch its own smart loudspeaker for home use – the HomePod – in time for Christmas have been delayed until early 2018, says Apple. You can sneak a preview at: **www.apple.com/uk/homepod**

We've come far since those Space Spartans first greeted us nearly 40 years ago, and thanks to the latest range of cloud-aware smart speakers, interactive hands-free help is now just a 'wakeword' away.

Chat Zone news

As mentioned last month, the *EPE Chat Zone* forum has reached its end of life and, by the time you read this, will have switched to 'read-only' mode for reference purposes. We aim to keep the forum online for the foreseeable future for retro-compatibility reasons with legacy projects dating back to 2005. *EPE* readers of all levels are invited to join us on **EEWeb.com**, where a sub-topic has been set up specially for *EPE Magazine*.

Legacy *EPE Chat Zone* users will find the pace more measured and it's worth reminding that the forum belongs to EEWeb and is not run by *EPE Magazine*: another way of saying that it's their rules, not ours! A number of *Chat Zone* users are already engaging with the broader EEWeb community forum, where a range of skilled and enthusiastic users are eager to help answer queries from their peers. We feel that many *EPE* readers will enjoy meeting a wider audience, although it's certainly true that some of the old **Chat Zone** forum features will be sorely missed, at least for the time being.

The EEWeb site is intended to be scalable and to get the best out of the new forum, topics are first and foremost classified by 'Category' such as Tools, Embedded Systems or Sensors. Therefore, when posting a new query, your post will firstly be listed in one of those broad categories. This helps keep the forum manageable and easy to sort through; it's also easy to view all messages dedicated to any category you may be interested in (passive components, for example).

As explained last month, it's necessary when composing your post to 'tag' it with a suitable sub-topic from the list in the right-hand column of the EEWeb page. To clarify, consider tags as keywords that help us to search and sort posts more intelligently rather than by slavishly following a sequence of posts. The tag field will auto-complete, so (very importantly for *EPE* readers!), simply start to type 'EPE' and our title will pop up and your query will appear in *EPE's* area. There is nothing to stop you multiple-tagging your post with something else instead of, or as well as, *EPE*. Once users are accustomed to this new way of posting, the EEWeb forum is a cinch to use.

At present, it is unfortunately not possible to embed inline images in posts; this is on a wish list but you can hyperlink to them. Websites such as **postImages.org** are designed for hosting images intended for forums and blogs, so this might be a stopgap for those wishing to create URLs for their images. At this point we must thank Clive 'Max' Maxfield, an editor at EEWeb, for helping the *EPE Chat Zone* to find a new home, which we hope, will become the reader's online go-to destination for the foreseeable future.

That's all for this month's *Net Work*. You can contact the author at: **alan@epemag.net** or write to the editor for possible inclusion in our *Readout* column at: **editorial@wimborne.co.uk**

PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

Four-digit, seven-segment LED display – Part 3

WE'VE BUILT a 24-hour clock with an LED display, but we want more! This month, we're going to add to the design and build a simple calculator – but, all the available GPIO pins have been used up; what to do?

In *Part 1* and *Part 2* of the four-digit seven-segment display, we built a simple clock, and you will need to re-read *Part 1* in order to build and understand this month's design. However, as just noted, we find we have a few problems. The biggest head scratcher is the number of available pins. We have used up all the GPIO pins on the PIC16LF1829 to control the LED display. So, to add extra functionality, we will need to figure out a way to connect any additional hardware.

Another problem to work around is the limited number of digits. There are only four digits on the display, limiting the range of numbers from 0 to 9,999. We also have decimal points on the display, which should allow us to display numbers as low as 0.001. For the moment, however, we will treat this as a software issue, which will be covered next month.

The keypad

We want to convert our design to behave like a calculator, which means we will need a keypad of some sort. Ideally, we want a keypad displaying the numbers from zero to nine, and keys for the basic arithmetic functions of addition, subtraction, multiplication and division. We also need a key for the equals sign to indicate we have completed entering our calculation. In total, this means fifteen keys. A 4×4 keypad would be ideal for this situation, giving us one extra key, which can be used as a clear display button, or maybe we could use it for the decimal point. Fig.1 shows the layout of these keys on a keypad, with the suggested numbering.

Now let's consider the behaviour we want for the calculator. We need to enter a first number followed by some mathematical function (add, subtract, divide and multiply) and then another number. Once the second number has been entered, we need some means of indicating we want the answer. The equals key tells the 'calculator' that we have entered the two values with some math function in between, and it's time to calculate and display the answer.

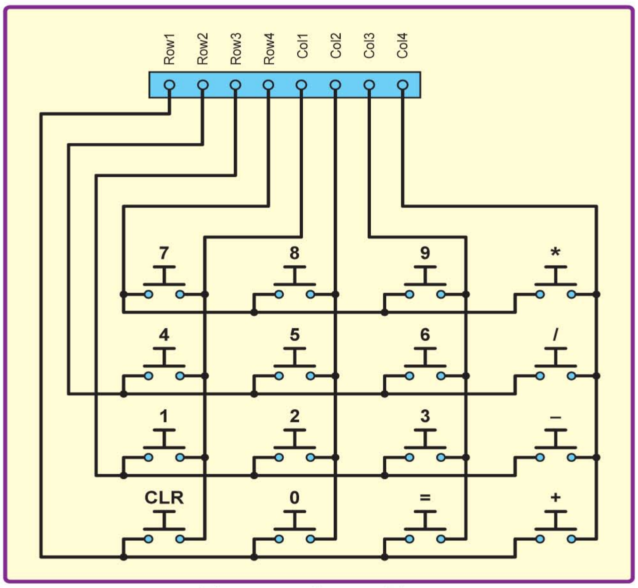


Fig.1. 4×4-keypad layout

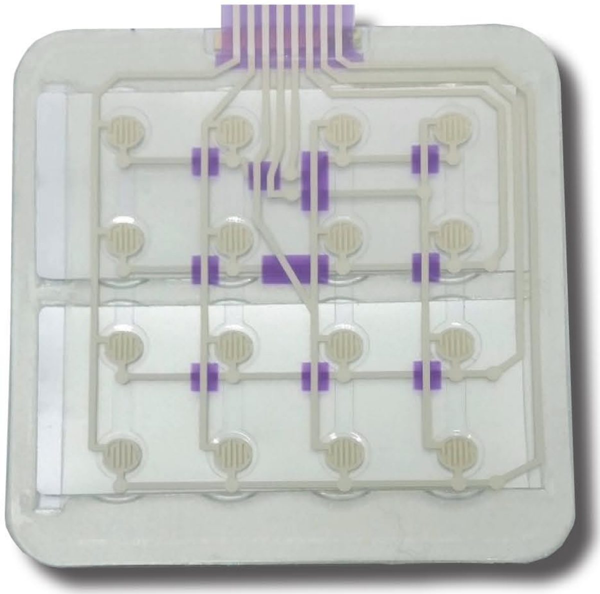


Fig.2. The underside internal working of a 4×4 keypad

There are going to be a few error scenarios that will need to be covered, which we will look at in the software next month. Examples include getting negative numbers, whole numbers rounding up and results that exceed the displays capacity. There are creative ways to work around these obstacles, but it's best to start simple and build on that.

The keypad operates in a 4×4 matrix. Fig.1 shows the schematic for the keypad, which is arranged into rows and columns. Fig.2 shows the underside internal workings of the keypad used in this project (the 4×4 AC3561 by APEM). The pads themselves are interleaved pieces of exposed copper. When a key is pressed, two pieces of copper are connected. The PIC microcontroller detects which row and column have been connected, allowing it to determine, which key was pressed.

The keypad's eight output pins are connected to each of these four rows and four columns. Typically, these keypads are configured by connecting all of the row and column pins to individual pins on a microcontroller. These pins are also connected to ground via a resistor, and are known as weak pull downs. The microcontroller cycles through each *column*, pulsing it high, and checking the state of each *row*. If a row pin goes high, then it knows a button has been pressed relating to that row and column.

There's just one problem here; we don't have eight pins available on the PIC. We have three options: 1) we could redesign our original design, cutting tracks and wires and adding in awkward connections, or 2) we could add a port extender, adding more GPIOs to our design, adding further complexity, or 3) something else!

In the original design, we switch between the common cathodes for each of the four digits. We could potentially hijack this behaviour and attach it to our row pins. This could cause some timing problems with our display. Not to mention, we're still four pins short.

All on one pin

In fact, we still have one pin available, which is currently used to program the PIC. Port RA0 is connected to the

ICSPDAT on the programmer. This is a digital data pin used for programming the PIC. It is possible to use this one pin to figure out what key has been pressed on the keypad. By using seven resistors, we present a unique voltage to RA0 for each key. RA0 will use an analogue-to-digital conversion (ADC) to translate these unique voltages into button presses.

By using a series of resistors that will behave as multiplexed voltage dividers, we can establish unique voltages for each key, and that unique voltage will be seen by the ADC module. We can then map these values to each key being pressed. The resistor values need to be calculated to ensure sufficient spacing between each voltage value. A 10-bit ADC typically yields an accuracy of about 2-3 bits. At 3.3V, this gives us around 10mV margin of error. Ideally, we want to ensure the difference between each value is much more than this.

Using an excel spreadsheet, I quickly worked out one set of values for these resistors, giving a decent spacing between each value. This could be optimised further. The spreadsheet will be included with the software download on *EPE's* website next month. Check it out and see if you can improve the values to reduce possible errors.

Fig.3 shows the schematic of our modified design. We use a 1kΩ pull-up resistor on RA0 to V_{CC}. This ensures when no button is pressed, our ADC value should be 1023 bits or 3.3V. When a button is pressed, what we are really seeing is a multiplexed voltage divider circuit. By pressing the number 2 on the keypad (Fig.1), we connect row 3 and column 2, which adds R13, R14 and R17 into the circuit.

A typical voltage divider circuit in shown in Fig.4, and the voltage divider equation is:

$$V_{out} = V_{CC} \times R2 /(R1 + R2)$$

Here, V_{out} is our ADC voltage. In the above '2' example, V_{CC} = 3.3V, R1 refers to the R11 1kΩ pull-up resistor, and R2 is the sum of R13, R14 and R17 (1kΩ + 1kΩ + 220Ω = 2.2kΩ). This should give us a value of 2.275V or 716 bits. When we capture this value, we now know the number 2 has been pressed. And we can add a debounce or delay afterwards to ensure we only recognise one press of the button (a particularly nice example of why debounce is important).

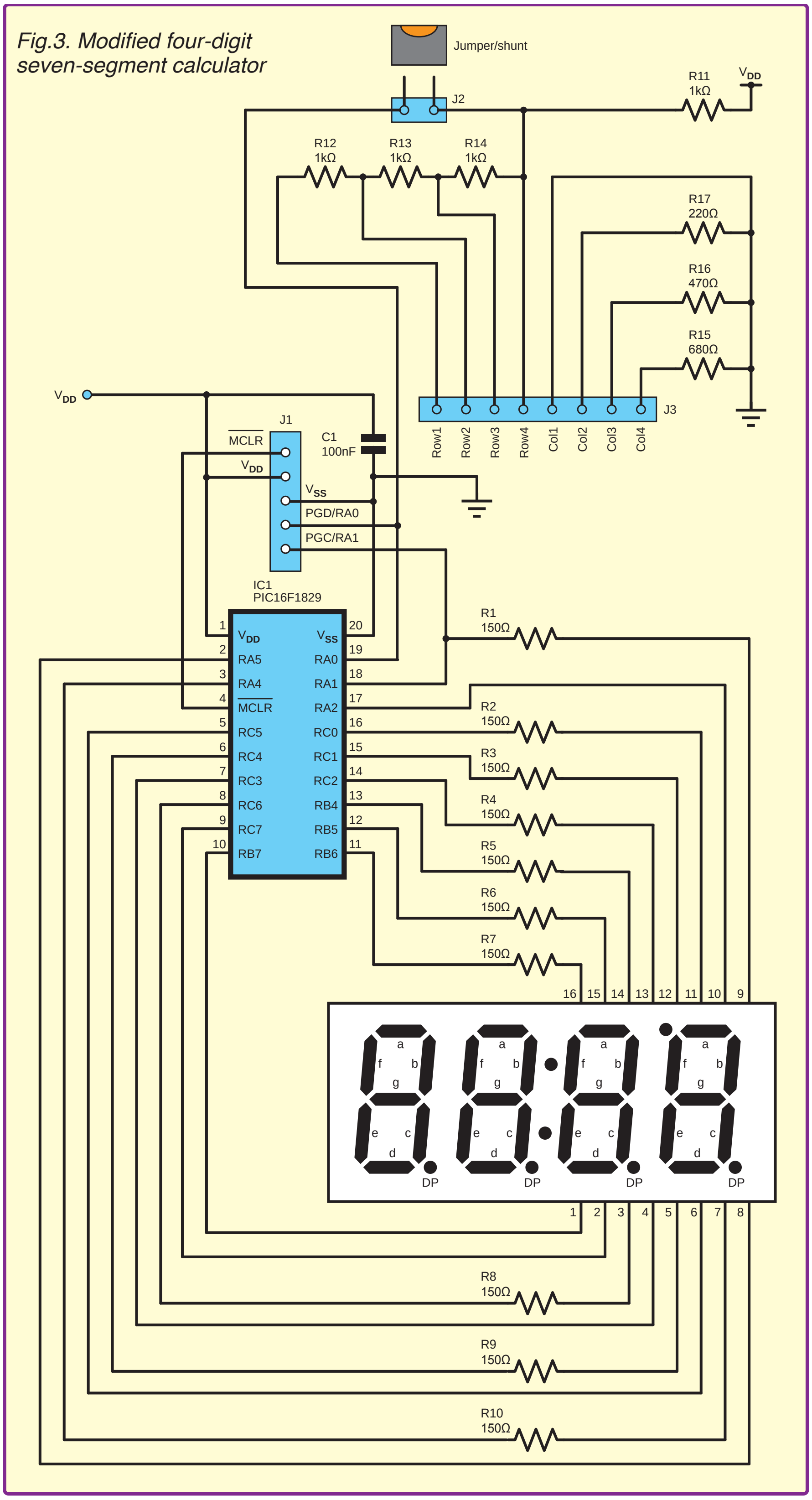


Fig.3. Modified four-digit seven-segment calculator

One small problem with programming

I mentioned earlier that RA0 is also a programming pin. The addition of the resistor network in Fig.3 poses problems when trying to program or debug the microcontroller. The 1kΩ pull up on R11 will hinder programming the board by making it harder for the programmer (eg, PICKit3 or ICD3) to output a logic low. In theory, we could scale the resistor values up so that they do not affect the programming. This could be done by multiplying each value by ten or a hundred. We would still get the same unique voltage for each key. The only problem here is that the resistors will start affecting the capture time of the ADC. The capture and conversion for the ADC needs to be quick to avoid problems on the display. Increasing resistor values will slow the voltage rise on the ADC pin as a key is pressed.

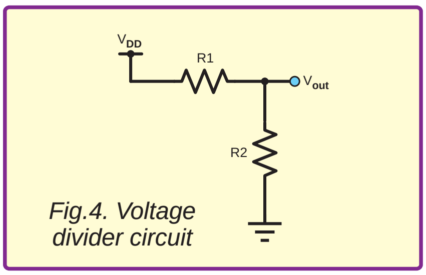


Fig.4. Voltage divider circuit

The only way to make this work is to disconnect the resistor circuit during programming. Soldering and

resoldering would be a nuisance, so I recommend using a two-pin header and a jumper or a shunt bar across the header to reconnect it – see J2 in Fig.3.

Constructing the circuit

To build the circuit, you need the following components:

Four-digit seven-segment display circuit from last month (December 2017)

Resistors

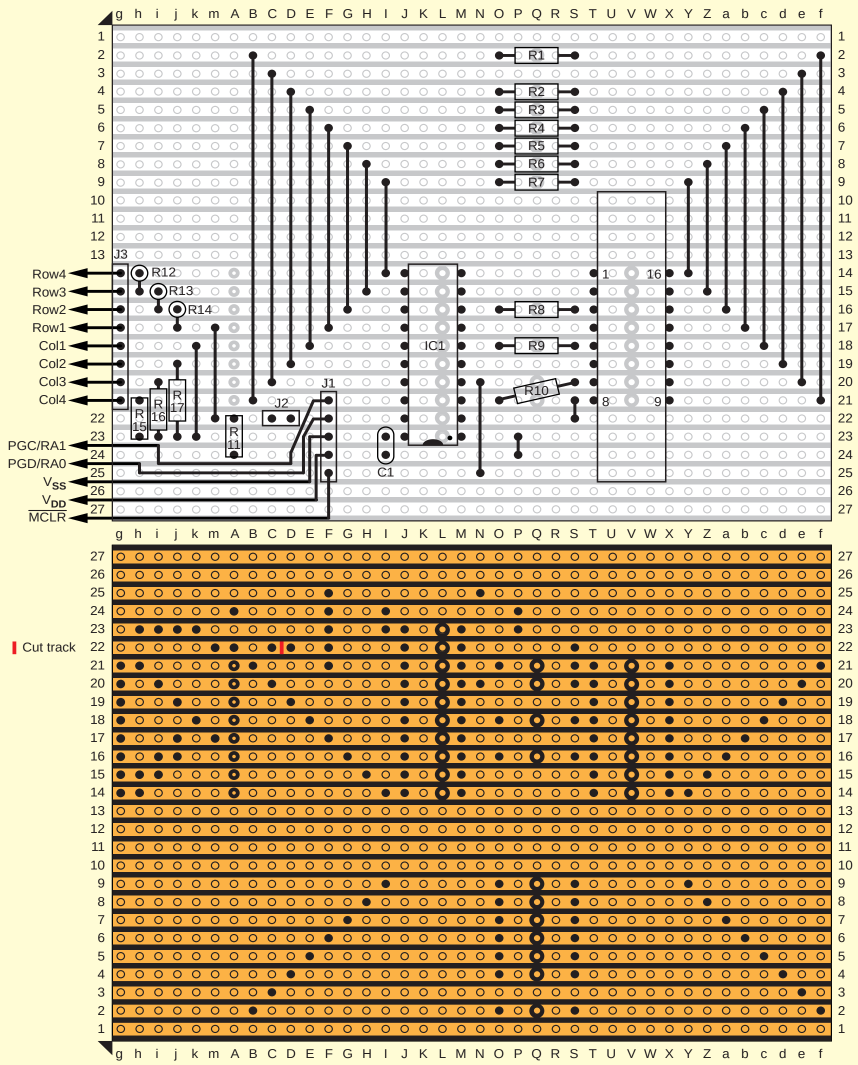
4 1kΩ (R11, R12, R13 and R14)
1 220Ω (R17)
1 470Ω (R16)
1 680Ω (R15)

Miscellaneous

1 2-pin header (J2)
1 Jumper or shunt bar (J2)
1 8-pin right-angled header (J3)
1 4×4 keypad (eg, AC3561 by APEM, as used here)

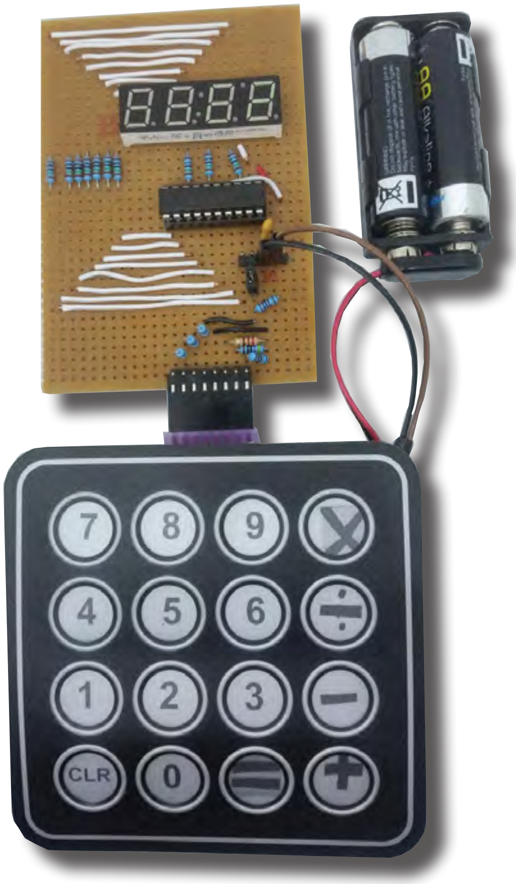
Fig.5 shows the veroboard layout for the components on the top side and the underside of the board. Don't forget to carefully make the jumper track cut between the holes on C22 and D22. Everything from Column B upwards is from the original design (excluding the connector J2). There are only nine components and two wires to add. The spacing for some of the resistors is a bit tight, so it might be easier to stand these up instead (see Fig.6).

Fig.6 shows the complete working calculator. The keypad from APEM comes with two silver inserts with the digits printed on them. These inserts originally came with other signs on them, which have been covered over for this project. Notice in Fig.6 that I have made my own mathematical symbols using a bit of black electrical tape. Feel free to move these around, but don't forget to make the adjustments in the software next month.



Note: the x-coordinates A to f match the layout from Part 1 (December 2017). The additional coordinates (g to m) indicate the new area of the board. ('l' – lower case 'L' has been skipped to avoid confusion with upper case 'I'.)

Fig.5. Veroboard project layout



It is interesting to consider this solution compared to the alternative methods of adding functionality to an existing design. It happens a lot more than I like to admit, where a project suffers from feature creep. Often this means a complete redesign, but in this case, a little bit of creative ingenuity saved us the hassle of creating a completely new design or some awkward wiring and track cuts.

All in all, I believe this method is a lot less complicated than the original method of controlling the keypad. There is a little more in the build, albeit only seven resistors. In fact, the true beauty of this design will reveal itself in the software next month. If we did have the necessary pins and we had to look at several inputs to discover what key has been pressed, this would add significant delays to the code, which would affect the behaviour of the LED display.

The software involves using an ADC to capture the input voltage and a function that maps that value to the corresponding button pressed. After that, it's a matter of calculating everything quickly enough without affecting the display.

Next month

We've now built the guts of the simple calculator; next month we'll look at how to program the microcontroller to capture the keys pressed on the keypad, display them on screen and perform simple calculations. As we mentioned last month, any delays in our code will cause the segment LEDs to flicker. This means our code will need to be quick enough that we don't notice what is happening in the background.

Not all of Mike's technology tinkering and discussions make it to print.

You can follow the rest of it on Twitter at *@MikePOKeeffe*, on the *EPE Chat Zone* or *EEWeb's* forums as *'mikepokeeffe'*

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Potential dividers and power supplies

RECENTLY on the *EPE Chat Zone* there has been some discussion on provision of multiple power supply voltages, power supply switching and regulator circuits, started by user ***Tuurbo46***. The discussion continued (under username ***Rocket Ron***) on the new *EPE* forum hosted by EEWeb (see this month's *Net Work*). This discussion has ranged over a number of related issues. Initially ***Tuurbo46*** posted on *EPE Chat Zone*, asking about obtaining a 2.5V supply from a 5V supply.

'I just need to confirm my circuit current understanding. Am I correct in thinking a 5V, 2A supply, with two series 10kΩ resistors to GND, can only supply 0.6mA from the potential divider? I would like to supply 2.5V and the possibility to source 100mA.'

After discussion moved to EEWeb and after ***Tuurbo46/Rocket Ron*** had received a number of helpful comments from other users on both forums, he posted more details of his requirements and updated his design ideas. In responses to ***Tuurbo46's*** initial question we will look at the nature of potential dividers and why they are generally unsuitable for directly providing supply voltages. This forum thread also raises other issues, which we may look at in a future article.

Fundamentals

The basic potential divider (Fig.1) comprises two resistors in series connected across a voltage source. Potential dividers can also be made using combinations of other components such as capacitors and inductors. The potential divider is a fundamental concept and basic 'building block' of electronic design. Therefore, discussion of the question posed by ***Tuurbo46*** leads us to introduce some basic circuit theory, which is useful to anyone designing, or endeavouring to understand, the operation of electronic circuits.

As the name suggests, the potential divider is a means of providing a lower (divided) potential (voltage) from a higher one. Thus, they act as attenuators – reducing the magnitude of a signal. Attenuation is commonly required in measurement, for example in high-voltage probes, which are used in conjunction with voltmeters or multimeters. Basic volume controls in analogue audio circuit use variable potential dividers. Other uses include biasing transistors, obtaining a voltage signal from a resistive sensor, such a thermistor, obtaining a reference voltage at exactly half the supply voltage (divide potential by two) for use as the mid-point for AC signals and setting the gain in op amp circuits. In the latter case, the potential divider sets the fraction (division) of the output fed back to the input. However, potential dividers are not suitable for some applications. In particular, they are generally unsuitable for providing power to circuits connected to their outputs – you *could* do it, but it is so wasteful of power that it is not worth doing. We will look the basic circuit theory behind potential dividers to explain why this is so.

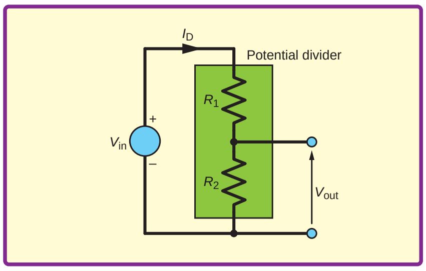

Fig.1. Potential divider

Equation

Refer to Fig.1, the current (I_D) in the potential divider resistors (R_1 and R_2) can be found using Ohm's law. Ohm's law is the relationship between the voltage (V) across a resistor (R) and the current (I) through it; specifically $I=V/R$. In this case, because the resistors are connected in series, the total resistance is the sum of the two, so Ohm's law gives the current in the divider as:

$$I_D = \frac{V_{in}}{(R_1 + R_2)}$$

The voltage dropped across resistor R_2 is the output voltage; again, by Ohm's law:

$$V_{out} = I_D R_2$$

Using the first equation for I_D, and substituting this into the equation above, we get the output voltage in terms of just the input voltage and resistor values

$$V_{out} = \left(\frac{R_2}{R_1 + R_2}\right)V_{in}$$

This is referred to as the 'potential divider equation'. From this equation, we see that because $R_1 + R_2$ must always be larger than R_2, V_{out} is always less than V_{in} by a factor determined by the resistor values. If we assume R_2 is n times the value of R_1, that is, $R_2 = nR_1$, the potential divider equation becomes:

$$V_{out} = \left(\frac{R_2}{nR_2 + R_2}\right)V_{in}$$

We can cancel the R_2 terms to get:

$$V_{out} = \left(\frac{1}{n+1}\right)V_{in}$$

The output voltage depends only on the relative values of the resistors, not on their absolute values. The current flowing through the divider does of course depend on the absolute resistor values, as does the power dissipation in the divider. If both resistors are the same value (so n = 1) the output voltage is half the input voltage. For example, if V_{in} = 5V and $R_1 = R_2$ = 10kΩ (as specified by ***Tuurbo46***) then V_{out} = 2.5V. With these resistors the current in the divider is (by Ohm's law) 5V/20kΩ = 0.25mA.

The current flowing through a potential divider will cause it to dissipate power. Electrical power is given by voltage times current (IV), which on applying Ohm's law can also be written as I^2R or V^2/R. The latter equation is generally most useful for finding the power in a potential divider because generally we know the applied voltage and resistor values. The 2 × 10kΩ divider across 5V discussed above consumes $(5V)^2$/20kΩ = 1.25mW of power.

Loaded

If we connect another circuit (a load) to the output of the potential divider the output voltage will change to some extent. This is an important consideration when deciding if a potential divider is appropriate, or when checking if we have chosen the most appropriate resistor values.

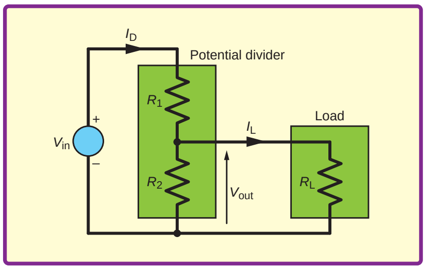

Fig.2. Loaded potential divider

The schematic of the loaded potential divider is shown in Fig.2. If we have a known load resistance we can work out the voltage across the load by finding the parallel combination of R_2 and R_L in Fig.2. We can then use this value in the potential divider formula to calculate a revised value for V_{out}. For two parallel resistors, R_2 and R_L, we have a combined resistance (R_p) given by:

$$\frac{1}{R_P} = \frac{1}{R_2} + \frac{1}{R_L}$$

So

$$R_p = \frac{R_L R_2}{(R_L + R_2)}$$

If we take our example potential divider (Fig.1 with two 10kΩ resistors) and connect a 10kΩ load, the effective value of the R_2 resistor in Fig.1 becomes 5kΩ (the parallel combination of two 10kΩ resistors). Using the potential divider formula, this gives an output voltage of 5 × 5/(10+5) =1.67V, a significant deviation (–33%) from the open-circuit output voltage of 2.5V. Adding the 10kΩ load has significantly reduced the output voltage. If the load is increased to 100kΩ then the voltage drops to 2.38V (–4.8% shift); and with a 1MΩ load the output is 2.49V (–0.5% shift). As a rule of thumb, a load resistance connected to a potential divider should be at least ten to one hundred-times larger than the resistor across which the load is connected to avoid the voltage shift from being too large.

Regulation

In the context of power supplies (***Tuurbo46's*** application) a shift in voltage under load is characterised by a parameter called 'load regulation'. A schematic of a generic regulator or power supply circuit is shown in Fig.3. Here, if the load current (I_o) varies then V_o should remain constant, but in practice it will vary to some extent.

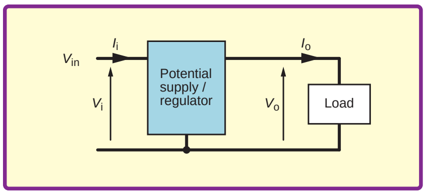

Fig.3. Power supply/regulator with load

The load regulation can be defined in terms of the ratio of change in V_o (written ΔV_o and pronounced 'delta V_o') produced by a change in I_o (ΔI_o)

$$\text{Load regulation} = \frac{\Delta V_o}{\Delta I_o}$$

This value is actually a resistance (voltage divided by current), which is the effective output resistance of the regulator (measured in ohms). We will discuss the concept of output, source or internal resistance shortly. Load regulation can also be expressed as the change in output voltage (ΔV_o) for some specified change in load current (typically a change from no load to maximum load) divided by the nominal or mean regulated output voltage (V_o).

$$\text{Load regulation} = \frac{\Delta V_o}{V_o}$$

This can be stated as a fractional value (eg, 0.002) or multiplied by 100 to give a % (eg, 0.2%).

Load regulation is usually specified on the datasheets of regulator IC and power supply units. Taking the LM317 regulator as an example (mentioned in ***Tuurbo46's*** discussion thread), the datasheet states a voltage change of typically 0.1% for a load current change of 10mA to 1500mA (low to full load). This regulation is much better than that provided by the 2 × 10kΩ potential divider, even with a 1MΩ load, where the load currents is in microamps.

Source

When considering power supplies, we do not always know the exact load resistance, but we may know the range of current that has to be supplied (***Tuurbo46*** quotes 100mA). When using a potential divider for anything, a useful reality check is to calculate the load current for a short-circuit load, that is R_L=0Ω in Fig.2. This is simply the current through R_1 if it is connected directly across V_{in}. In this case, we have 5V/10kΩ = 0.5mA.

As ***Tuurbo46*** indicated in his question, the potential divider cannot supply a higher current than this into a grounded resistive load; and at this current the voltage across the load is zero. This immediately proves that the potential divider in Fig.1 is unsuitable for the specified power supply application, which requires 100mA at 2.5V.

Calculating the short-circuit output current of the potential divider is useful because it helps us find the effective internal resistance, or source resistance, of the voltage source formed by the potential divider. We also need the open-circuit voltage (the unloaded potential divider output voltage), which we already know is

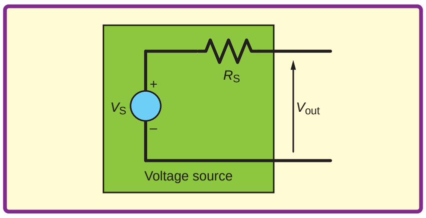

Fig.4. Thévenin equivalent circuit

2.5V for our example. From this we can find our source resistance from 2.5V/0.5mA = 5kΩ. This is equal to the parallel combination of the two potential divider resistors.

We can then replace the potential divider with the equivalent circuit shown in Fig.4, in which for our case the source voltage (V_S) is 2.5V and the source resistance (R_S) is 5kΩ. This circuit behaves exactly like the potential divider in terms of output voltages and currents.

This idea is not just applicable to potential dividers; any combination of independent voltage sources, current sources and resistors, for which we can designate two output terminals, is equivalent to a single voltage source and series resistor at those terminals.

Thévenin

This is an important piece of circuit theory known as 'Thévenin's theorem' – the circuit in Fig.4 is called the 'Thévenin equivalent circuit'. The same approach can be used with AC circuits where all the sources in the original circuit are at the same frequency, in which case we work in terms of impedance and can include capacitors and inductors in the original network. One limitation of this approach is that the total power dissipation in the equivalent circuit is *not* the same as in the original.

To obtain the Thévenin equivalent for any suitable circuit we find the open-circuit output voltage and then the short-circuit output current. The open-circuit voltage is used as the equivalent source voltage and the open-circuit voltage divided by the short-circuit current gives the source resistance. This and other types of equivalent circuit are widely used in circuit analysis and design, and are the underlying theory behind well-known concepts such as input and output impedance.

Fig.5 shows the Thévenin equivalent circuit of a potential divider connected to a load resistance. The load and source resistance form another

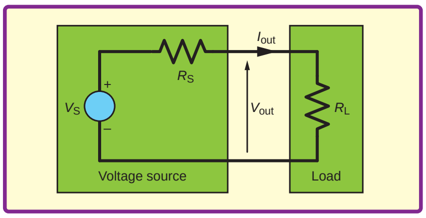

Fig.5. Equivalent circuit for the potential divider with load

potential divider, which determines the load voltage. If we again look at a load of 10kΩ, the potential divider equation for Fig.5 becomes:

$$V_{out} = \left(\frac{10000}{10000+5000}\right) \times 2.5 = 1.67\text{V}$$

As expected, this gives the same output voltage as calculated above using the parallel resistors approach.

Variation

Use of the equivalent circuit makes it easy to calculate the variation in output voltage as load current varies. We have already noted that obtaining 100mA is impossible with our example circuit, so we will assume a more realistic requirement of current from 50µA to 100µA. For I_L = 50µA, R_S will drop 50µA × 5kΩ = 0.25V, so the output will be about 2.25V. At 100µA the output will be 2.0V. This level of voltage change (20%) is much larger than would be generally acceptable for supply voltages.

Potential dividers can provide very accurate division of an input voltage – depending on the tolerance of the resistors or other components used to form the divider. However, the divider should be connected to a circuit, that takes as little current as possible from the divider to prevent voltage shifts occurring due to loading. Typically, in many circuit designs, these are inputs to op amps, ADCs or other devices with very high input impedances, which present very little load to the divider.

In some cases, such as bipolar transistor biasing, the load currents may be higher, in which case more care has to be taken to ensure the divider is not loaded. The rule of thumb mentioned earlier (ten to hundred times the current in the divider compared to the load) provides a useful starting point. The actual voltage shifts due to loading in any application can be calculated or estimated and used to determine appropriate resistor values. The lower in value the resistors used, the 'stiffer' the voltage output will be (lower source resistance) but more power will be consumed in the divider. This may be an important consideration in some applications where low power consumption is of particular importance.

Efficiency

We can use the equivalent circuit in Fig.5 to work back to a potential divider that might be able to deliver the required current in the original power supply scenario – and then look at the power consumed by the divider. For the sake of an example, we will assume that R_S must drop no more than 2% of 2.5V at 100mA (we do not know ***Tuurbo46's*** requirements in this respect, but 2% is much worse load regulation than that provided by a typical voltage regulator IC, such as the LM317 mentioned above). 2% of 2.5V is 0.05V, so the maximum value of R_S is 0.05V/100mA = 0.5Ω. As the potential divider suggested by ***Tuurbo46*** has equal resistors we can use twice the R_S value (1.0Ω) for both resistors. This is not practical due to the current and power dissipation in the divider. With no load, the divider current is 2.5A (5V/2Ω) and the power dissipated by the divider with no load is $V^2/R = 5^2/2.0$ = 12.5W – extremely wasteful, given that at 2.5V a 100mA load consumes 0.25W (2.5V × 0.1A). We can calculate the efficiency of power supply as:

$$\text{Efficiency} = \frac{P_O}{P_O + P_L},$$

Here, P_O is the output power and P_L is the power loss (power consumed by the supply circuit). For the potential example just given, ignoring voltage shifts, we have approximately P_O = 0.25W and P_L = 12.5W. So this 'potential divider power supply' has about 2% efficiency.

For a linear regulator IC, wired as shown in Fig.3, we can approximate $P_O = I_O V_O$ and $P_L = I_O(V_I - V_O)$, so:

$$\text{Efficiency} = \frac{P_O}{P_O + P_L} = \frac{I_O V_O}{I_O V_O + I_O\left(V_I - V_O\right)} = \frac{V_O}{V_I}$$

For a linear regulator supplied from 5V and outputting 2.5V, the efficiency is 50%, very much better than the potential divider and with a far better load regulation. The LM317 linear regulator mentioned above has a minimum $V_I - V_O$ of 3V, so it would need a larger input voltage and would consequently have a lower efficiency. Standard linear regulators are not very efficient, but are still much better than potential dividers. Greater efficiency can be achieved using 'Low Drop Out' (LDO) linear regulators, which require much lower $V_I - V_O$ to operate (for example, in the 100mV range, rather than several volts). Still higher efficiency can be obtained using switching regulators (often around 80% or more).

Configurations

Tuurbo46's requirement is for a system with multiple power supply voltages. This requires two regulators. The regulators could be connected in parallel (as in Fig.6) or in series (as in Fig.7). In both cases V_{O1} is higher than V_{O2}. Which is the most efficient? With linear regulators, at first it might seem like the series configuration is more efficient because V_O/V_I is smaller for the second regulator, so its own efficiency is better. However this power is supplied by the first regulator, so we have to multiply the efficiency of the second regulator by that of the first to get the overall value. With linear regulators the efficiency of both configurations is the same. For switching regulators their efficiency does not vary much with input voltage, so the series configuration is less efficient because of the multiplying effect of efficiency when one regulator supplies another.

For both switching and linear regulators the series configuration has the disadvantage that the first regulator has to handle all the current for both power supplies, whereas for the parallel version each regulator only has to handle the current for its individual output. However, if regulator 1 is a switching regulator and regulator 2 is linear, the series configuration may be a good option due to the improved efficiency of operating the linear regulator with a lower input voltage.

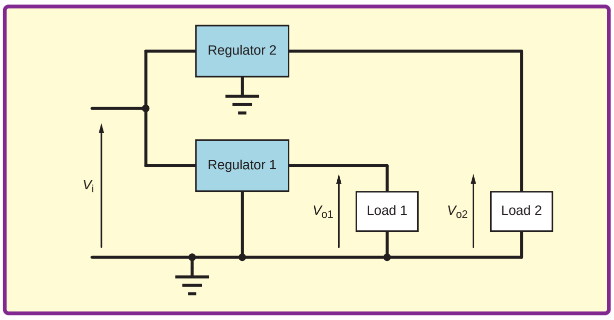

Fig.6. Two regulators in parallel for a system requiring two supply voltages

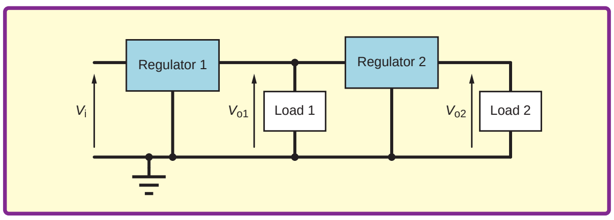

Fig.7. Two regulators in series for a system requiring two supply voltages

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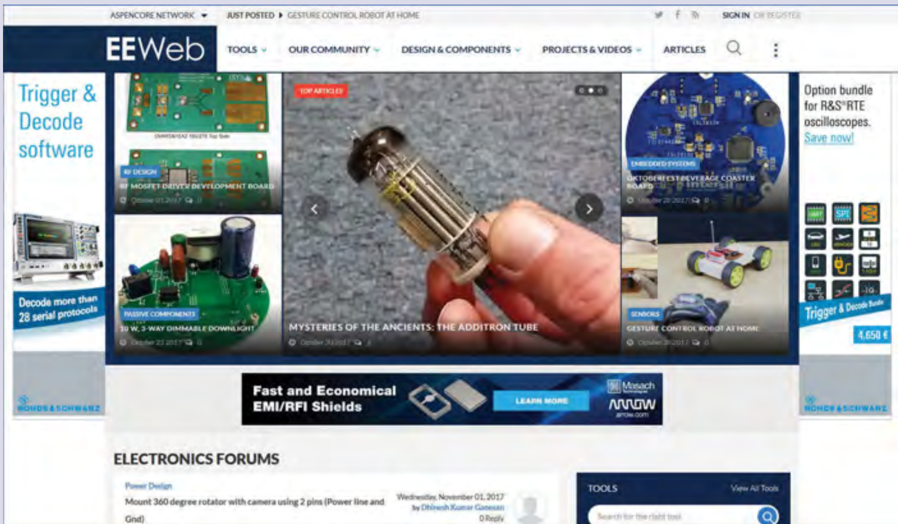

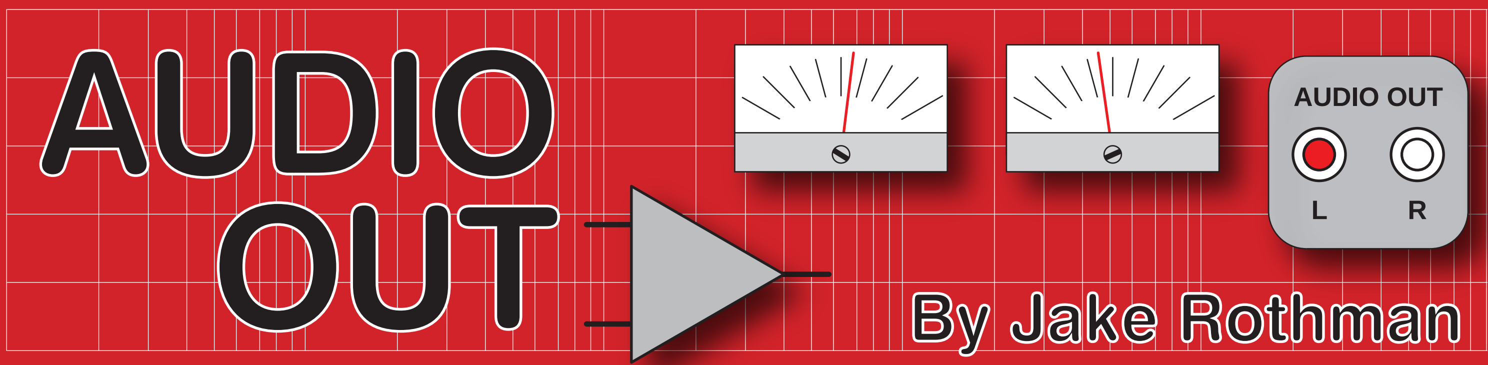

Railing against convention – Part 2

Shiftier

I didn't quite have space to finish off my comments on bias shift last month – so here are a few more thoughts.

As an alternative to full regulation on a single-rail supply, only the supply feeding the bias network, input stage and voltage amplifier stages is regulated and only the output stage is fed with the full unregulated voltage. In this case, the upper output transistor of the push-pull stage doubles as a series-pass voltage regulator, effectively blocking the ripple and droop. A voltage loss/headroom of around 10V at no output, reducing to 4V at full output, is necessary; reducing the power output. James Sugden described this in *Hi-Fi News* (*The Class Problem*, November 1967). His main expertise was class-A amplifiers, so voltage sag wasn't a problem, therefore the loss was less. If a separate higher voltage regulated rail is provided, this loss can be avoided altogether, but ripple break-through at clipping will still occur. With a typical power supply regulation figure of 20%, the output power is reduced to 65% – remember, power is proportional to V^2, and that is why the power loss seems excessive.

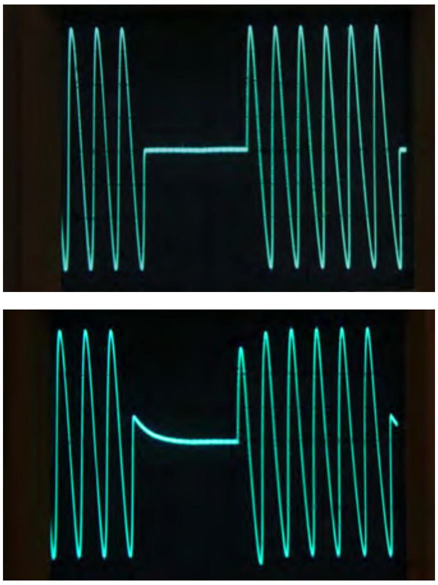

Fig.5 a) (top) Clean tone burst; and b) generation of a low-frequency envelope due to AC coupling.

Capacitor conundrums

Prolonged asymmetrical clipping can cause a DC charge to build up across output capacitors, moving the centre bias point. This is a problem with all capacitor coupling and bootstrapping, causing recovery problems after overload. This problem is compounded by the asymmetry of most music signals. However, this is less of a problem for Hi-Fi amps because they are generally not overloaded. All systems, including dual-rail, with differing AC and DC gains have this problem to some degree and will exhibit a low-frequency shift on the output under tone-burst testing. This is shown in Fig.5a and 5b. Another test is to use an unequal mark-space ratio square wave to see if there is any DC level-shift. (This should be checked with both extremes of mark-to-space ratio.) Any generated shift will often be seen as an odd excursion of the loudspeaker cone.

Asymmetry

In power amplifiers with low quiescent current (I_q), the output capacitor ensures the same I_q current flows through both output transistors in the push-pull stage, rather than some being diverted through the loudspeaker. In a directly coupled dual-rail amplifier, without an output capacitor, a small DC offset can unbalance the currents through the output transistors, increasing crossover distortion. This effect was discussed with regard to the Bailey Amplifier as early as 1969 (*Wireless World*, Oct 1969) and the Equin amplifier (*Elektor*, April 1976). An offset current flowing through the speaker also wastes power, which is bad in any battery-powered circuit.

Overcoming asymmetry in circuits is easily achieved in single-rail systems, since the bias point can simply be moved to ensure symmetrical clipping. To do this in a dual-rail circuit requires different rail voltages. Quad did this on their 34 pre-amplifier by having +8.6 and –9.4V rails. Circuit configurations that generate an offset voltage with dual-rail designs, such as a single transistor, JFET or the dual-complementary pair, will need this. Long-tailed pairs are invariably used for dual-rail amplifiers, increasing complexity and making life boring for the circuit designer.

Power losses

The electrolytic output capacitor (in single-rail systems) causes power loss at low frequencies due to its reactance and equivalent series resistance (ESR). For example, in the MX50 amplifier (*EPE*, May 2017) a

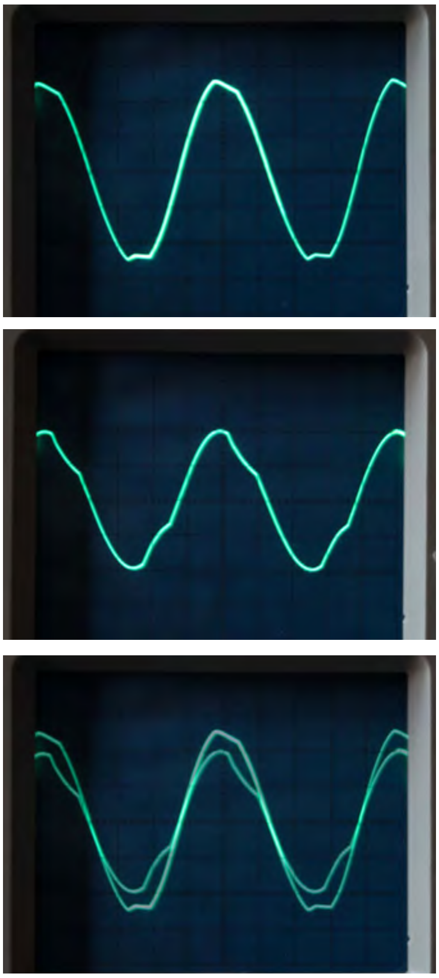

Fig.6. Demonstration of power-limited output caused by approx 2000µF coupling capacitor driving full power into a 4Ω load at 20Hz: a) (top) direct coupling (no capacitor); b) (middle) 2000µF capacitor coupling; and c (bottom) comparison of both curves.

Fig.7. The 'head-bang' test demonstrates the resonant frequency of a loudspeaker and damping effects – thanks to Isabella Rothman for modelling the technique.

non-polarised capacitor of 1880µF (4 × 470µF 35V in parallel) was inserted in series with the output. At 20Hz, and feeding a 4Ω load resistor, the maximum power of 78W_{rms} was reduced to 36W. Fig.6 shows these waveforms slightly clipped with the characteristic slope of reactive power limiting. The reactance caused most of the loss, being 4.23Ω and the ESR, 0.05Ω. In theory, the peak dissipation of the output devices could be increased due to phase shift between the current and voltage, but the capacitor's phase angle is generally much less than that due to the loudspeaker's varying impedance.

Single-rail circuitry does require more capacitors for DC blocking, and the half-rail polarising voltage is advantageous if tantalum types are employed, since their distortion is reduced.

(Do note that it's a myth that coupling capacitors can be completely avoided in dual-rail DC-coupled audio circuits, since switch clicks and pot scratching still occur due to small offsets. Capacitors still have to be used to block these.)

Fig.8. A massive output capacitor has no distortion, but distorts one's bank account.

Head banging and damping

Some engineers claim an output capacitor ruins the damping of the bass driver's fundamental resonance. This is not the case, since the impedance of the capacitor (X_c = 0.7Ω for 4700µF at 50Hz) is much less than the impedance of the voice coil at the speaker's resonant frequency. If you need practical proof of this, listen to the resonance of a speaker using the 'head bang test' (shown in Fig.7) by banging a speaker next to one's ear. This demonstrates the speaker's resonance, which will be heard as a short, low-frequency tone. Banging it again with the terminals short circuited (to simulate the low output impedance of an amplifier) will damp the speaker and it will sound completely dead. Doing it again, but with a 2200µF capacitor connected across the speaker terminals will be equally damped. This shows the subjective issues with output capacitors are not due to reduced damping.

Remember, the impedance of the speaker rises at resonance so the effect of the capacitor is even less at this frequency compared to the speakers nominal impedance. This gives rise to the paradox that for a given capacitor, the bass roll-off is at a lower frequency than that calculated for the speakers stated impedance value. Because of this effect, output capacitors are not as detrimental as believed when small closed-box Hi-Fi speakers are used. However, if the capacitor is too small there will be a bump in the frequency response at the resonant frequency and rapid bass loss below. There is an optimum value for a given speaker/box volume for best bass. This became a technique developed by KEF who included a bipolar electrolytic capacitor in series with the bass unit. (Note that ported enclosures are best driven directly – no output capacitor.)

Massive attack

The Sugden A48 went overboard in curing output power losses caused by the output capacitor. It used a huge 10,000µF output capacitor (hence, very low reactance) to enable the amplifier to drive low impedances. Doug Self also showed that making the output capacitor very large (100,000µF, eg the one shown in Fig.8.) meant that the capacitor distortion became insignificant.

Negative feedback

One way of reducing the problems associated with output capacitors (in single-rail designs) is to include them in the amplifier's negative feedback loop. Taking negative feedback after the output capacitor almost eliminates its detrimental effects, apart from the low frequency power loss. The basic idea is shown in Fig.9, where the negative feedback is split into a DC path and an AC path to set the gain via the output capacitor. To reduce the capacitor distortion effectively the resistance of the DC path needs to be 10x the AC path so there is 20dB of feedback remaining across the output capacitor. For dual-rail amplifiers (if a capacitor is used) a bipolar capacitor or two standard electrolytics connected back-to-back is needed since there is no polarising voltage.

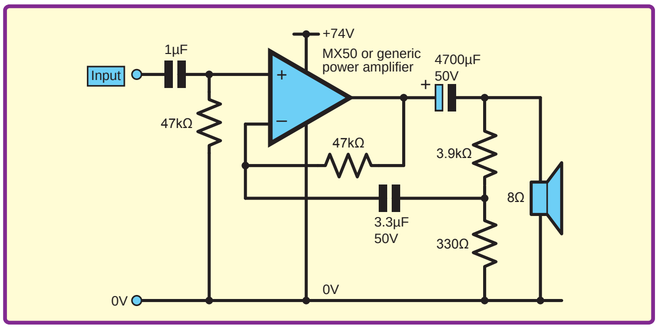

Fig.9. Incorporating a cheap output coupling capacitor in a feedback loop reduces its distortion and output impedance to that of a large expensive one. Engineering is often a case of brains vs material.

Next month

In Part 3 we will conclude this short series by applying some of the ideas discussed to the MX50 amplifer.

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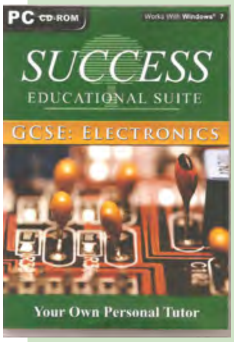

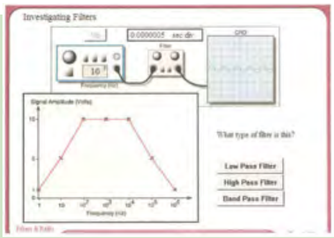

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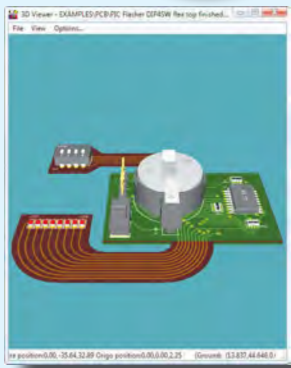

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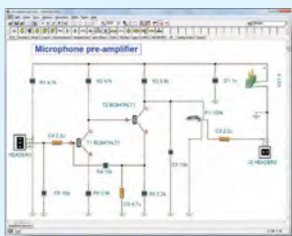

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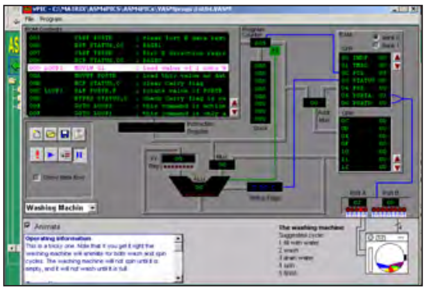

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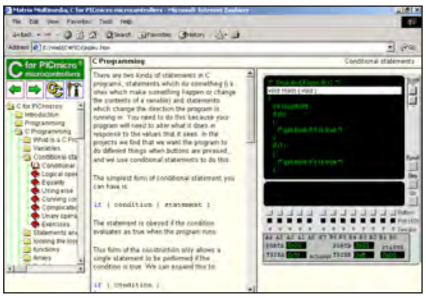

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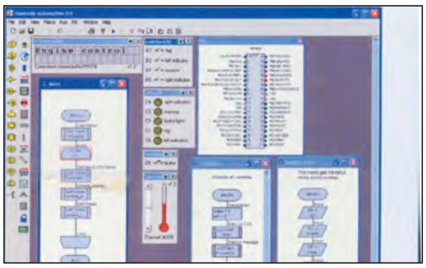

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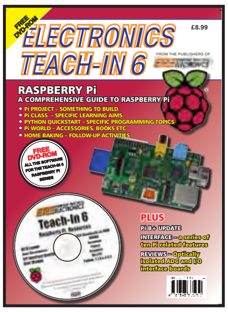

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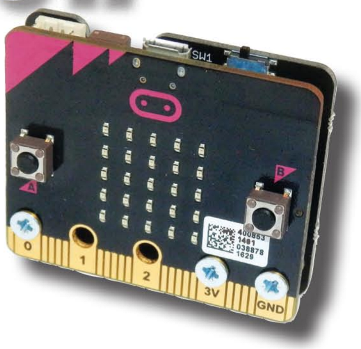

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PYTHON CODING ON THE BBC MICRO:BIT
Jim Gatenby

Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

Among the many topics covered are: The main features of the BBC micro:bit including a simulation in a Web browser screen; The various levels of programming languages; The Mu Editor for writing, saving and retrieving programs, with sample programs and practice exercises; REPL, an interactive program for quickly testing lines of code; Scrolling messages, creating and animating images on the micro:bit's LEDs; Playing and creating music, sounds and synthesized speech; Using the on-board accelerometer to detect movement of the micro:bit on three axes; A glossary of computing terms.

This book is written using plain English and avoiding technical jargon wherever possible and covers many of the coding instructions and methods which are common to most programming languages. It should be helpful to beginners of any age, whether planning a career in computing or writing code as an enjoyable hobby.

118 Pages — **Order code PYTH MBIT** — **£7.99**

GETTING STARTED WITH THE BBC MICRO:BIT
Mike Tooley

Not just an educational resource for teaching youngsters coding, the BBC micro:bit is a tiny low cost, low-profile ARM-based single-board computer. The board measures 43mm × 52mm but despite its diminutive footprint it has all the features of a fully fledged microcontroller together with a simple LED matrix display, two buttons, an accelerometer and a magnetometer.

Mike Tooley's book will show you how the micro:bit can be used in a wide range of applications from simple domestic gadgets to more complex control systems such as those used for lighting, central heating and security applications. Using Microsoft Code Blocks, the book provides a progressive introduction to coding as well as interfacing with sensors and transducers.

Each chapter concludes with a simple practical project that puts into practice what the reader has learned. The featured projects include an electronic direction finder, frost alarm, reaction tester, battery checker, thermostatic controller and a passive infrared (PIR) security alarm.

No previous coding experience is assumed, making this book ideal for complete beginners as well as those with some previous knowledge. Self-test questions are provided at the end of each chapter, together with answers at the end of the book. So whatever your starting point, this book will take you further along the road to developing and coding your own real-world applications.

108 Pages — **Order code BBC MBIT** — **£7.99**

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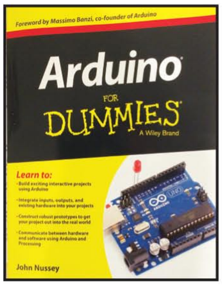
Teach-In 2016

Exploring the Arduino



ARDUINO FOR DUMMIES
John Nussey

Arduino is no ordinary circuit board. Whether you're an artist, a designer, a programmer, or a hobbyist, Arduino lets you learn about and play with electronics. You'll discover how to build a variety of circuits that can sense or control real-world objects, prototype your own product, and even create interactive artwork. This handy guide is exactly what you need to build your own Arduino project – what you make is up to you!

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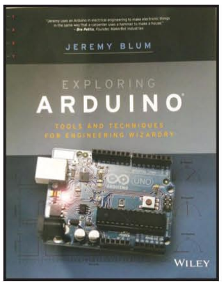

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Jeremy Blum

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Exploring Arduino shows how to use the world's most popular microcontroller to create cool, practical, artistic and educational projects. Through lessons in electrical engineering, programming and human-computer interaction this book walks you through specific, increasingly complex projects, all the while providing best practices that you can apply to your own projects once you've mastered these. You'll acquire valuable skills – and have a whole lot of fun.

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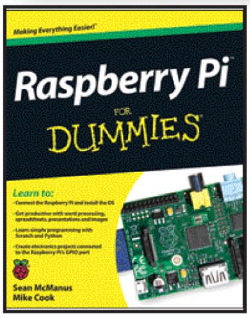

RASPBERRY Pi FOR DUMMIES
Sean McManus and Mike Cook

Write games, compose and play music, even explore electronics – it's easy as Pi! The Raspberry Pi offers a plateful of opportunities, and this great resource guides you step-by-step, from downloading, copying, and installing the software to learning about Linux and finding cool new programs for work, photo editing, and music. You'll discover how to write your own Raspberry Pi programs, create fun games, and much more! Open this book and find: What you can do with Python; Ways to use the Raspberry Pi as a productivity tool; How to surf the web and manage files; Secrets of Sonic Pi music programming; A guide to creating animations and arcade games; Fun electronic games you can build; How to build a 3D maze in Minecraft; How to play music and videos on your Raspberry Pi.

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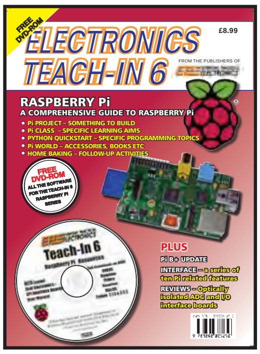

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Max's Cool Beans

By Max The Magnificent

A roll of the dice

Sometimes I have so many ideas buzzing around my poor old noggin that I don't know whether I'm coming or going. Let's start with the fact that one of my current hobby projects is to build a *Countdown Timer* using Nixe tube-esque displays called Lixies (see *EPE*, November 2017). I'm using 12 of these bodacious LED-based displays, which are organised in pairs to represent the years, months, weeks, hours, minutes, and seconds remaining to some auspicious event, such as my 100th birthday, for example.

The thing is, as much as I like watching my little Lixies performing their magic ('Show me a flashing LED, and I'll show you a man drooling,' as I always say), even I would get bored watching a simple countdown after a year or two. Thus, I decided to add to the visual interest by throwing in a few special effects. The first of these was to generate a series of random numbers (Fig.1).

As you can see in this video (**http://bit.ly/2yBWulT**), we start by generating a new random number for each digit, and then display all 12 digits for a short period. We repeat this action several times, after which we hold the final value for one second, and then we start all over again. I don't know about you, but I think this looks rather tasty.

It's all in the timing

The Lixies are based on WS2812 tri-colored LEDs (the same devices that are used in Adafruit's NeoPixels). These little scamps can be daisy-chained together, which means that you can drive a bunch of them using a single pin on your microcontroller (an Arduino Mega, in the case of my *Countdown Timer*). A Lixie comprises 10 thin plastic sheets, each of which is illuminated by two WS2812 devices, so each Lixie contains 20 WS2812s. Since my *Countdown Timer* boasts 12 digits, this means we end up with 240 WS2812s daisy-chained together.

I've described how WS2812s/NeoPixels work in previous columns. All we need to remember here is that when we specify the RGB color values we wish to associate with a WS2812, these values are stored in an array in the Arduino's memory. It's only when we use the `show()` function that all of this data is streamed out to the physical LEDs.

Without wandering off into the weeds, it would be advantageous for us to know how long it takes to update our 12-digit display. In most cases, when using an Arduino, this would be quite easy. The Arduino has a `millis()` function that returns the number of milliseconds that have elapsed since the program started to run. So, given a choice, we might write a sketch (program) like this:

```
unsigned long startTime;
unsigned long endTime;
unsigned long elapsedTime;

later...

startTime = millis();
lixies.show();
endTime = millis();
elapsedTime = endTime - startTime;
```

Fig.1. Generating random numbers

We could then use the Arduino's `Serial.print()` function to display the elapsed time. There's just one small problem here, which is that the register in the Arduino that contains the number of milliseconds accessed by the `millis()` function is updated using an interrupt. The reason this is a problem is that the first thing the `show()` function does is to disable the Arduino's interrupts (it re-enables them after it's finished streaming the data to the LEDs).

I didn't know anything about this when I first started using WS2812s. It took me ages to work out why my programs were producing weird and wonderful results. The solution I opted for in this case was to measure the duration using an oscilloscope. The first step was to generate an appropriate sketch. All this does is loop around generating a new random number for each Lixie, outputting the result, and then waiting 10ms before doing it all again (you can see this sketch here **http://bit.ly/2AGRKiL**).

The next step was to set this program running and observe the results on the oscilloscope. The results are illustrated in Fig 2. The green blocks reflect the time when the data is being streamed out to the Lixies. As you can see from the vertical cursors and the delta (Δ) value at the bottom, each burst takes about 7.2ms.

On the one hand, 7.2ms seems quite a lot. On the other hand, it's less than 1/100th of a second, which means we can do all sorts of things and still update our display multiple times each second if we so desire.

One thing that did surprise me is that the delays between the green blocks are about 11.5ms (11.48 to be precise). As I mentioned earlier (and if you check the program), we have specified a 10ms delay ourselves, so where does the extra 1.5ms come from? The only other thing we do is to generate a new random value for each digit. Personally, I'm surprised that generating 12 random values would consume 1.5ms, so this is something I plan on looking into to see if there's a way I can streamline things.

Maybe, just maybe, I was wrong

In an earlier *Cool Beans* column (see *EPE*, December 2017), I explained how I wanted to be able to easily experiment with varying the variables used to control my

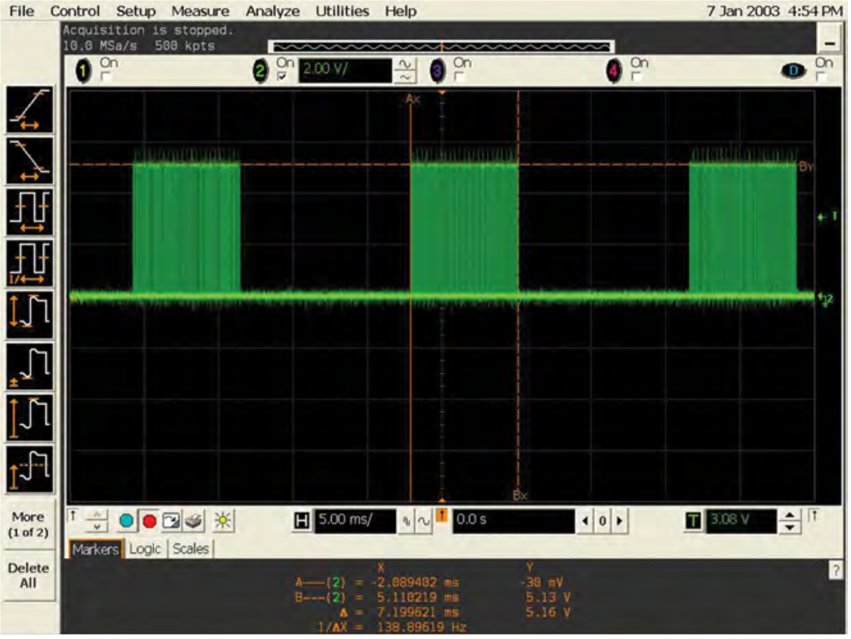

Fig.2. Bursts of data being streamed out to the Lixies

Countdown Timer effects. As part of this, I discussed my 'Hardware Rules, Software Drools,' philosophy with regard to creating a physical (hardware) control panel as opposed to it's virtual (software) equivalent.

Well, I ended up building my hardware control panel (see *EPE* January 2018), but I think I may have had a change of heart. The more I noodle on this, the more I realise that using the Arduino's Serial Monitor to implement a command-line interface could be rather efficacious.

One of the reasons I fought so hard against using a virtual control panel is my belief that it would slow my programs to a crawl. This is based on earlier experiences where I've used `Serial.print()` commands to output the values of variables over and over again while cycling around a loop. More recently, I've been informed that there's actually minimal overhead so long as you aren't actually transmitting or receiving data.

Suppose I have three variables I wish to control – Initial rate (I), Sustain Time (S), and Decay Time (D). When my program starts running, it could assign default values to these variables (say 100, 400, and 500, respectively). Meanwhile, I could display a '> ' character/space combo in the Serial Monitor window on my PC.

Now, suppose I enter 'S 1000' followed by pressing the Enter/Return key on my keyboard. Upon being informed that new serial data was available, my sketch could use this to update the value of my Sustain Time variable to be 1000. If I were to enter a '?' character, my sketch could respond by displaying the current values of all my variables, after which my Serial Monitor window might look like the following:

```
> S 1000
> ?
I = 100
S = 1000
D = 500
>
```

For your delectation and delight, there's a *Serial Input Basics* thread on the Arduino forum that describes using the Serial Monitor to input and output textual and numerical data in excruciating detail (**http://bit.ly/2xHiz4D**).

The more I think about this, the more I like it. In fact, I'm thinking about looking at some way to quickly and easily include this type of functionality in all my programs.

Measure twice, cut once...

Following some water leaks, we recently had to have a lot of work done on our house. As part of this, my wife (Gina the Gorgeous) decided we needed some new kitchen countertops. I was working from home while these were being installed. Between the sound of drills and stone saws, I heard the happy chatter of the two 20-something lads as they performed the installation. Then silence fell.

...always!

This wasn't the kind of silence that portends the arrival of something exciting, fun, and interesting; it was the other sort. It was a silence that all but screamed tidings of grim forebodings. I wandered into the kitchen to see what was going on. The two lads were standing in front of the hole they had cut for the stove top. The hole was about two inches wider than it should have been.

They perform these installations all the time. They couldn't understand how they had come to make such an obvious mistake. I could. They had gotten blasé about things and had forgotten the old proverb 'measure twice, cut once' (the Russian version is 'measure seven times, cut once'). This saying was originally associated with carpentry and needlework, but it applies to almost everything we do, including designing electronic systems. It's always worth rechecking your measurements before taking any actions based on them. In the case of something that's mission- or safety-critical, in addition to measuring two or more times, multiple people should independently perform the same measurements and then compare results. Doing this would have saved the aforementioned lads a lot of heartache when they came to communicate the situation to their boss.

So long, and thanks for all the fish

Now we come to the part I've been dreading. I hate to have to tell you that this is going to be my last *Cool Beans* column in *EPE*. The problem is that I'm the Editor in Chief of the **EEWeb.com** website, and this is now consuming all of my time.

EEWeb is the place to see and be seen with regard to electronic design and verification tools, and our forums. In fact, you may have heard from Alan Winstanley that the *EPE Chat Zones* are shutting down (sad face), but that everyone is moving over to the **EEWeb.com** forums (happy face). Furthermore, Alan has set up a special *EPE Magazine* group in the forums just for us (see page 47 in this issue of *EPE* for more details).

If you've enjoyed my *Cool Beans* columns in *EPE*, you'll be happy to hear that I also write articles about my hobby projects and anything else that piques my interest over on EEWeb. For example, take a peek at my *Don't be the Second Banana* offering (**http://bit.ly/2AHQXOE**), which introduces all sorts of interesting nuggets of knowledge, such as the difference between the standard banana (*Bananus Vulgaris*) and its antipodean counterpart (*Bananus Australis*).

And so, I bid you *adieu*, but remember that I'm only ever an email away: **max@clivemaxfield.com**. Until we meet again, have a good one!

PCB SERVICE

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Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

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DEC '16		
Universal Loudspeaker Protector	01110151	£12.88
9-Channel Infrared Remote Control	15108151	£16.42
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JAN '17		
High-performance Stereo Valve Preamplifier	01101161	£17.75
High Visibility 6-Digit LED Clock	19110151	£16.42
FEB '17		
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MARCH '17		
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APRIL '17		
Microwave Leakage Detector	04103161	£8.00
Arduino Multifunctional 24-bit Measuring Shield	04116011 }	£17.75
– RF Head Board	04116012 }	
Battery Pack Cell Balancer	11111151	£9.00
MAY '17		
The Micromite LCD BackPack	07102122	£11.25
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JUNE '17		
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AUG '17		
Micromite-Based Touch-screen Boat Computer with GPS	07102122	£10.45
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(36 × 13mm)	16109162	£5.60
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DEC '17		
Precision Voltage and Current Reference – Part 2	04110161	£15.35
JAN '18		
High-Power DC Motor Speed Controller – Part 1	11112161	£12.88
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FEB '18		
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– Control Board	11112161	£12.88
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Next Month

MARCH '18 ISSUE ON SALE 1 FEBRUARY 2018

Stationmaster

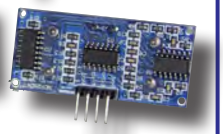
Want to build a walk-around throttle for your model railway layout? We have a design that is easy to build yet provides useful features such as adjustable inertia, emergency braking and PWM control. It includes a separate hand controller, which you can plug into various sockets around your layout.

SC200 audio amplifier – Part 3

In this third instalment, we'll provide the SC200's performance details, the required power supply, and the testing and set-up procedure. Plus, we'll explain how to build lower-power versions of the amplifier.

Low-cost Electronic Modules – Part 2 and 3

We've a double bill for you next month. In our second article on cheap pre-built electronics modules we're focusing on the HC-SR04 ultrasonic distance sensor module. We describe how the module works and show how it can be used as a hallway monitor or door sentry.



In the third article, we'll look at computer interface modules. If you want to connect a microcontroller to your PC, or interface with a microSD memory card then the low-cost modules that are now available make life really easy!

Teach-In 2018 – Part 6

Next month's *Teach-in 2018* will look at audio frequency tests and measurements. Our project will feature a low-distortion audio frequency test signal source.

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *Electronic Building Blocks, PIC n' Mix* and *Net Work*.

Content may be subject to change

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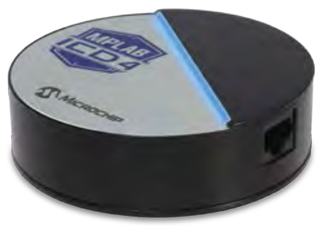

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